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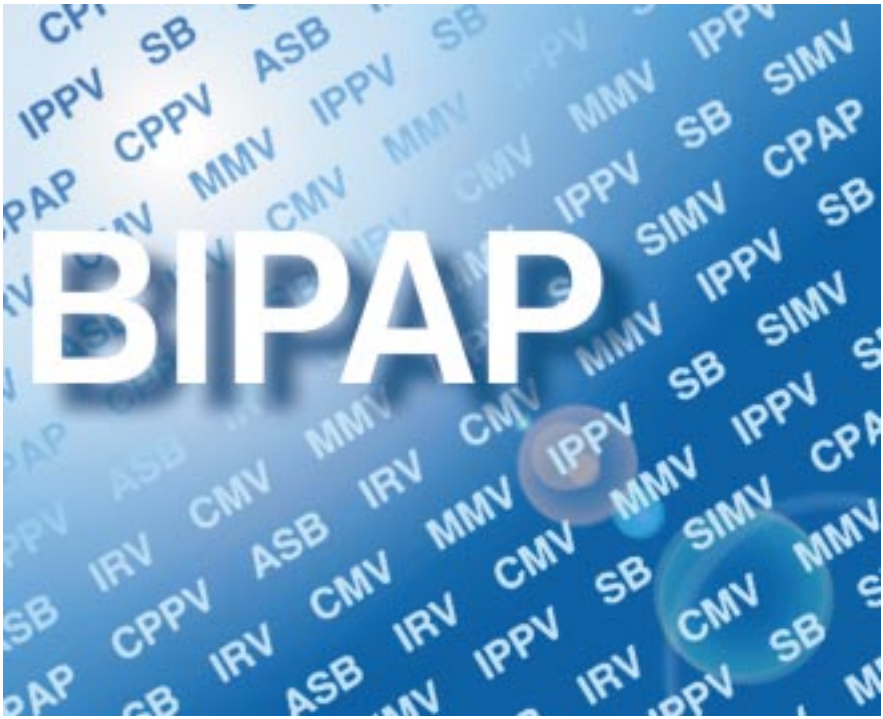

Two Steps forward in Ventilation

Ernst Bahns

Important Note:
Medical knowledge changes constantly as a result of new research and clinical experience. The author of this introductory guide has made every effort to ensure that the information given is completely up to date, particularly as regards applications and mode of operation. However, responsibility for all clinical measures must remain with the reader.

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BIPAP –
Two Steps Forward in Intensive-Care Ventilation

An introductory guide to Evita ventilation

Modern ventilators enable therapy to be specifically directed at a wide range of respiratory disorders and can do far more than just maintain vital functions. The continued development of pneumatics and electronics and, above all, of computer technology means that today selective measures can be taken to manage problems with the control and mechanics of ventilation and with gas exchange.

Because there has been so much technical development, it is extremely difficult to keep track of all the therapeutic measures available. For instance, there are now more than a dozen different ventilation modes. The accompanying expansion in the number of terms used has tended to create confusion rather than clarity. It is, therefore, essential to ask the question:

Do we really need yet another new ventilation mode?

The answer can only be »yes«, provided that an attempt is also made to tackle some of the confusion. Complexity could be reduced, if it is possible to use the same mode from the beginning of ventilation through to weaning.

The success of ventilation therapy depends on several factors. It is an important factor that ventilation is provided with minimum intervention at the right time and with the right intensity. Ventilation therapy should adapt to the changing needs of the patient. Ideally, such a »universal ventilation mode« would accompany the patient throughout ventilation therapy.

This introductory guide covers two basic aspects of modern intensive-care ventilation. It describes new approaches for hospital staff and presents new information on the effect on patients. Wherever possible the guide avoids the use of abbreviations and technical terms.

One of the main principles in the design of Evita was to simplify ventilation. Following the same principle, this introductory guide aims to make ventilation easier to understand and easier to use.

Outline

The BIPAP[1)] (Biphasic Positive Airway Pressure) ventilation mode is a modern ventilation method which has been an important feature of the Evita ventilator since it was first introduced. This guide is designed to make the subject easy to understand.

Research which has been published in medical literature on the theory and clinical applications of BIPAP ventilation is summarized in simplified form in this introductory guide to assist busy clinical staff.

Since both the theory and the practice have developed from well-known principles, BIPAP does not demand that users think along entirely new lines. All that is required is an interest in new ideas.

The introductory guide is divided into four sections, as follows:

1. Description of BIPAP:
This section gives a brief outline of how BIPAP was developed and how it is classified according to performance.

2. BIPAP and conventional ventilation:
This section compares BIPAP with standard mandatory ventilation and spontaneous breathing.

3. Setting BIPAP:
This section describes how BIPAP operates in the Evita 1 ventilator and how this has been simplified for the Evita 2 ventilator.

4. Using BIPAP:
This section deals with intensive-care ventilation using BIPAP, gives instructions for weaning and discusses special applications.

A bibliography is provided at the end of the guide.

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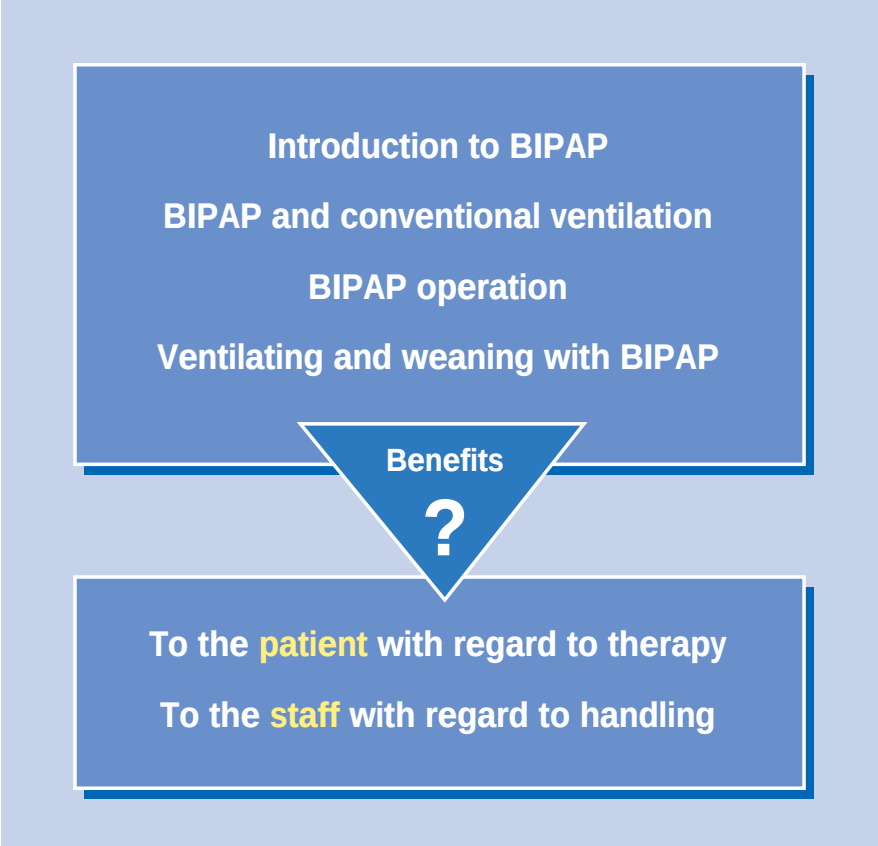

Fig. 1: Aims and structure of the BIPAP booklet.

Four sections are divided into sub-sections. Each sub-section deals with a separate topic on two pages with text and figures.

BIPAP in brief

BIPAP ventilation ranges across the whole spectrum from purely mechanical ventilation to purely spontaneous breathing. This range can cover the entire course of therapy from intubation to the completion of weaning. For this reason BIPAP has come to be known as a »universal ventilation mode«.

In contrast to conventional ventilation, BIPAP does not feature separate modes for controlled ventilation and spontaneous breathing, but merely variations of the same ventilation mode. The boundaries between the variations are completely flexible as they are defined primarily by the patient's ability to breathe spontaneously.

The diagram in Figure 2 shows that the lung being ventilated with BIPAP can be thought of as a balloon with two forces acting on it. The positive pressure generated by the ventilator, combined with the negative pressure produced by the inspiratory muscles, produce a flow. In BIPAP ventilation these two forces never oppose one another.

BIPAP's broad spectrum gives staff more freedom and flexibility for ventilation therapy.

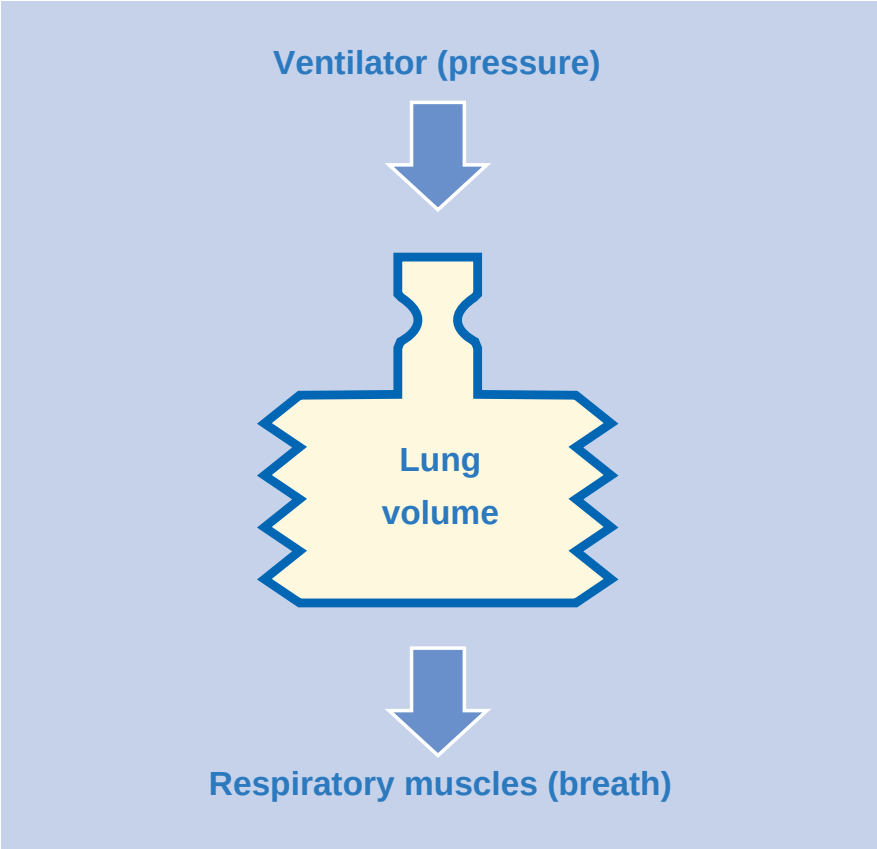

Fig. 2: Mechanical model of the lungs illustrating BIPAP ventilation.

Ventilation of the lungs involves two forces. The ventilator generates a positive pressure whilst the inspiratory muscles produce a negative pressure. The two forces combine to produce a change of volume in the lungs.

A story in brief: The origins of BIPAP

BIPAP was first described in a study published in 1985 by a group led by M. Baum and H. Benzer and it was incorporated in the Evita ventilator in the same year. Earlier studies conducted by Downs et al. used the term APRV (Airway Pressure Release Ventilation) [7] to describe a method of ventilation which used the same mechanical principle as BIPAP, but started from a different premise.

The authors describe BIPAP as pressure-controlled ventilation with freedom of respiration and spontaneous breathing on two CPAP levels. Figure 3 is from the study published by Baum et al. [1].

The workgroup of Baum represented a new approach to ventilation techniques. Before 1989, though ventilation modes employed a mixture of mechanical ventilation and spontaneous breathing (augmented ventilation), they were all based on the same principle for maintaining minimum ventilation, namely mechanical breaths alternating with spontaneous breaths.

The clinical problems which arose from alternating between mechanical ventilation and spontaneous breathing were the starting point for the development of BIPAP: patients often failed to accept the enforced respiratory rate or the interruption of their spontaneous breathing by the mandatory breaths.

Baum and Benzer realized that BIPAP was particularly important from the clinical point of view because ventilation was accurately matched to the patient's spontaneous breathing and because it was straightforward to use. These advantages were thought to be particularly significant for weaning, because there was no alternation between pure mechanical ventilation and augmented ventilation. Decisions about when to start the weaning process become totally unnecessary – with the new BIPAP mode weaning is possible right from the start.

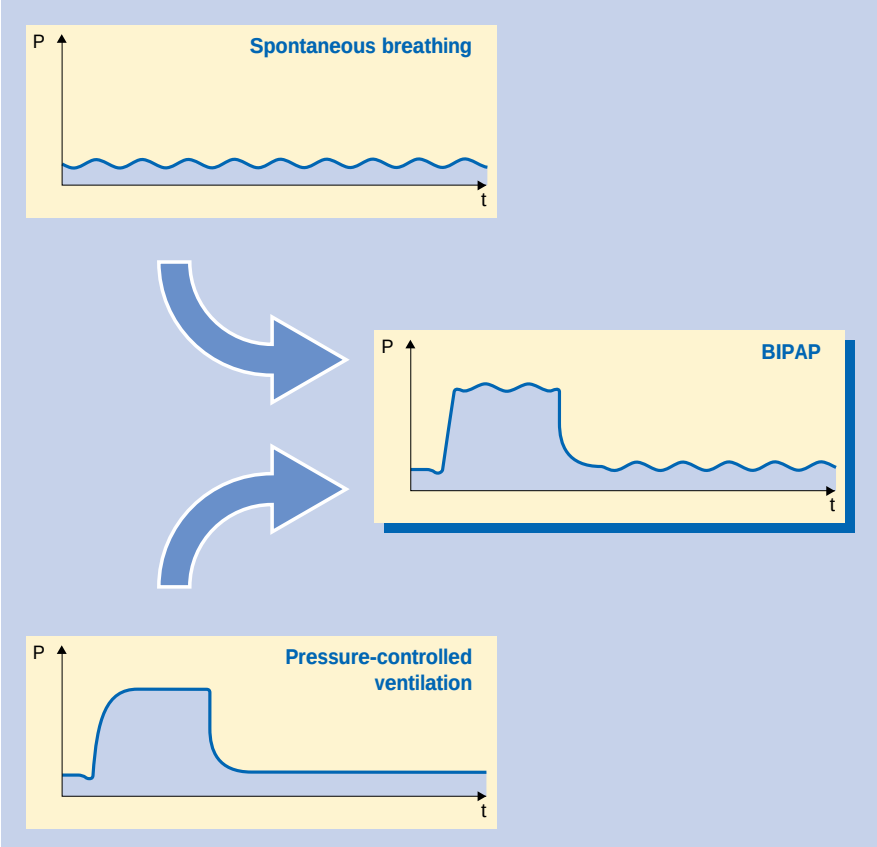

Fig. 3: Schematic view of BIPAP principles.

The figure shows the principle of mixed mechanical ventilation and spontaneous breathing. In contrast to conventional ventilation, mechanical and spontaneous breathing occur at the same time in BIPAP.

Simply a matter of form: A versatile ventilation mode

BIPAP can take many forms depending on how it is being used. On the one hand, it can provide pressure-controlled ventilation in a system which always permits unrestricted spontaneous breathing but it can also be viewed as a CPAP system with time-cycled changes between different CPAP levels.

Basically there are two processes involved when ventilating the lungs with BIPAP as shown in Figure 2. The flow is generated in two ways – firstly, mechanically by alternating between two pressure levels and, secondly, by the action of the inspiratory muscles. The relative contribution made by these two processes governs the form of BIPAP. The graph in Figure 4 is taken from a paper by Hörmann et al. [5]. It describes the BIPAP spectrum in conventional ventilation terminology and classifies the various forms according to the proportion of mechanical ventilation involved.

1. IPPV-BIPAP with no spontaneous activity on the part of the patient. Ventilation is pressure-controlled and time-cycled. All ventilation activity is carried out by the ventilator.

2. SIMV-BIPAP with spontaneous breathing on the lower pressure level only. Increased pressure at the upper level delivers a machine-generated flow.

3. »Genuine« BIPAP: Here, the patient breathes spontaneously at both the upper and the lower pressure levels. Mechanical ventilation is superimposed on the spontaneous breathing as a result of step changes in pressure, but spontaneous breathing is not impeded.

4. BIPAP after the two pressure levels become the same (CPAP). Spontaneous breathing is continuous. The patient takes over the total ventilation.

The next section describes BIPAP ventilation in two ways: firstly compared to conventional controlled ventilation and then in conjunction with supported spontaneous breathing.

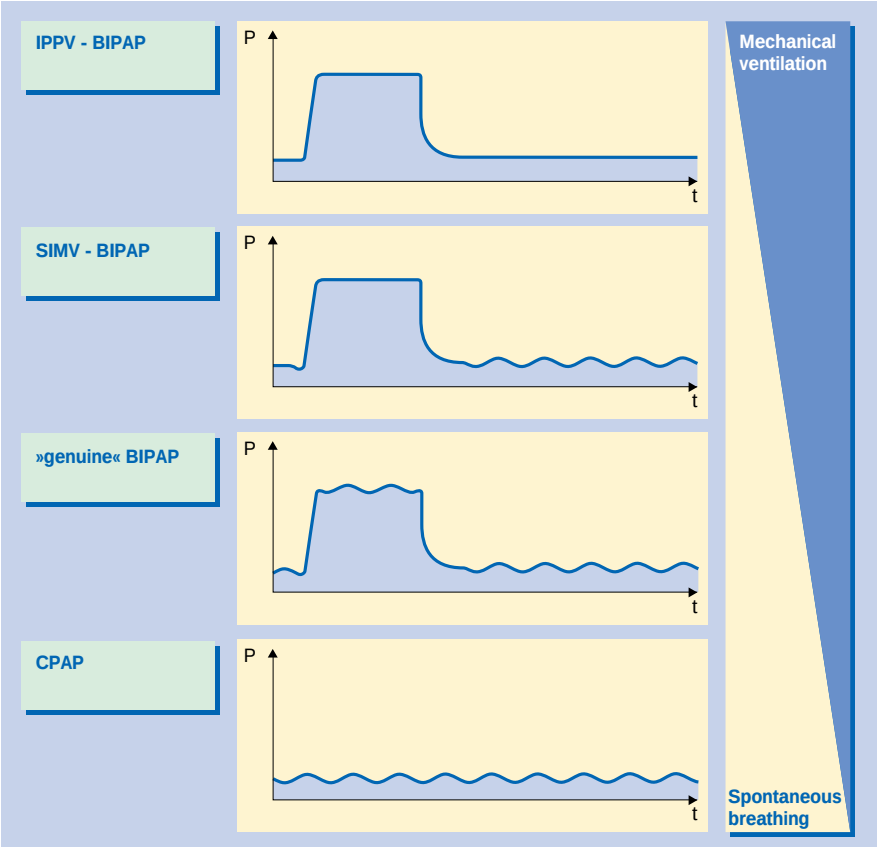

Fig. 4: BIPAP forms described in conventional ventilation terms.

The various forms of BIPAP are classified according to the respective proportions of mechanical ventilation and spontaneous breathing. IPPV-BIPAP: no spontaneous breathing; SIMV-BIPAP: spontaneous breathing only at lower pressure level; »genuine« BIPAP: continuous spontaneous breathing at two pressure levels; CPAP: continuous spontaneous breathing, both pressure levels are equal.

A need for order: Conventional variety of definitions

BIPAP is a single ventilation mode which covers the entire spectrum from mechanical ventilation to spontaneous breathing. Conventional ventilation has a variety of ventilation modes, each of which covers a specific range of applications.

Conventional ventilation is divided into three categories with different modes depending on the relative proportion of mechanical ventilation. Figure 5 shows these categories.

In controlled ventilation all the work is performed by the ventilator. With pure controlled ventilation, the interval between mandatory breaths is completely independent of the patient.

Augmented ventilation involves contributions by both the machine and the patient and thus represents a mixed mode of mechanical ventilation and spontaneous breathing. Conventional augmented ventilation has two varieties: intermittent and pressure-supported ventilation.

In intermittent ventilation, mechanical breaths alternate with spontaneous breaths and the frequency and duration of these breaths can be selected by clinical staff. In pressure-supported ventilation, on the other hand, the frequency and duration of mechanical support depends on the patient and only the intensity of the machine support is set.

It is clear, therefore, that conventional ventilation has two important characteristics which distinguish it from BIPAP. Firstly, it usually involves alternating between various modes during therapy and, secondly, there are two different modes of augmented ventilation, not just one.

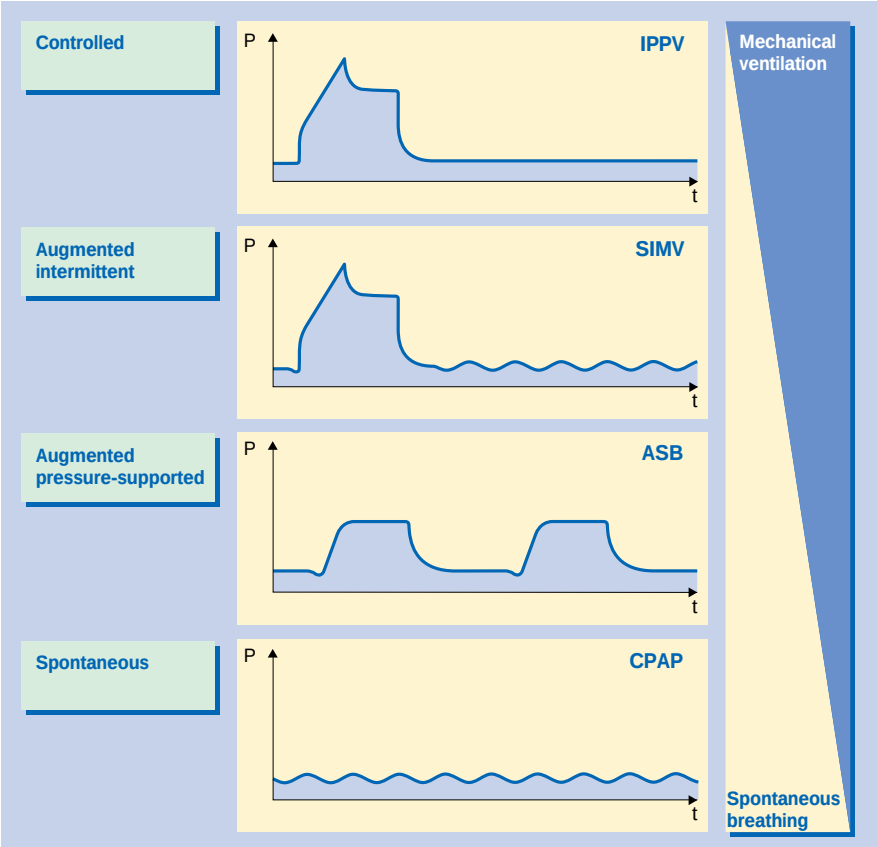

Fig. 5: The spectrum of conventional ventilation.

The ventilation modes are classified according to the relative proportions of mechanical ventilation and spontaneous breathing. Controlled: pure mechanical ventilation without spontaneous breathing; intermittent augmented: alternate spontaneous breathing and mechanical ventilation; augmented pressure-supported: machine support of spontaneous breathing.

Ventilation strategies: Volume or pressure control

The classification of ventilation modes according to their contribution to breathing activity, given in Figure 6, is particularly relevant in the weaning process. Ventilation modes can also be classified according to primary objectives and strategies of the therapy. Volume-constant and pressure-controlled ventilation differ in the way they react to changes in lung mechanics. Both forms of ventilation have specific advantages and disadvantages for particular areas of application.

The figure shows the spectrum from volume-constant ventilation to pressure-controlled ventilation as it is offered by Evita 2.

Volume-constant ventilation is the term used when the set tidal volume is administered while pressure is maintained below a preset maximum. Pressure-controlled ventilation is the term used to describe a situation where the preset maximum airway pressure is set at plateau values and the flow is administered for the duration of the inspiratory time. An intermediate mode, which is possible with the Evita ventilator, is pressure-limited ventilation where the maximum airway pressure chosen is such that the set tidal volume can still just be administered. The first three waveforms in the graph illustrate volume-constant, pressure-limited and pressure-controlled ventilation.

BIPAP is a variation of pressure-controlled ventilation. It differs from conventional pressure-controlled ventilation as far as the mechanical breaths are concerned in that spontaneous breathing is always possible. BIPAP permits spontaneous breathing not only during expiration, but also during mandatory breaths. This is shown in the fourth waveform in the graph.

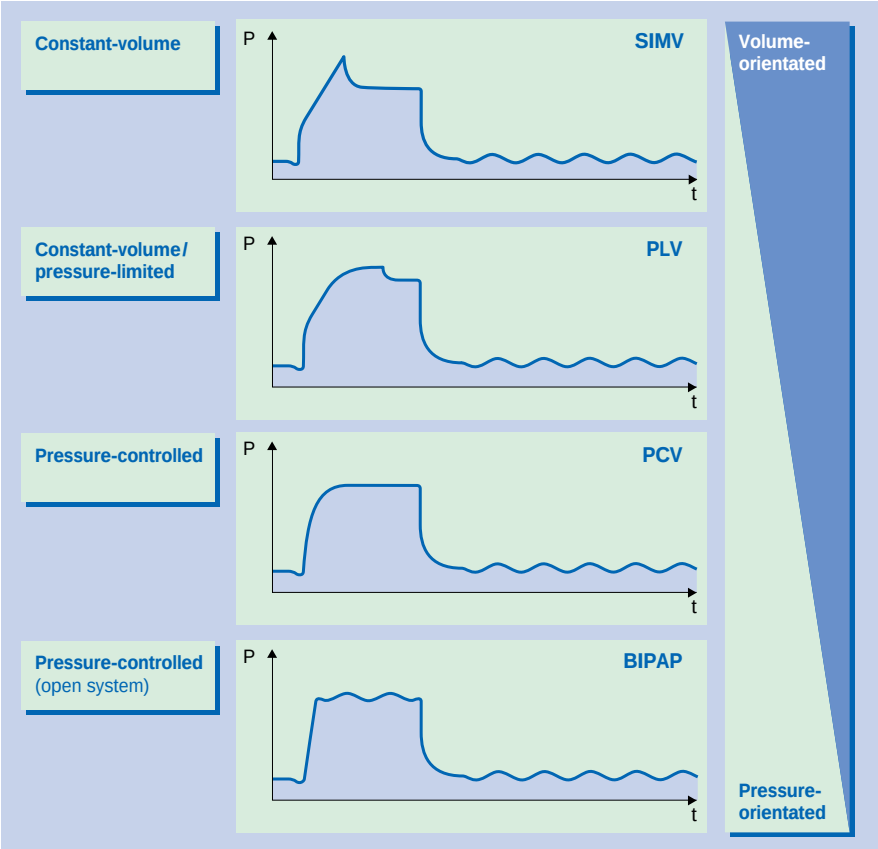

Fig. 6: The spectrum of volume-constant and pressure-controlled ventilation.

The different modes of ventilation are classified in terms of volume and pressure control. Volume-constant: administration of a constant tidal volume with constant flow; volume-controlled/pressure-limited: constant tidal volume administered with decelerating flow; pressure-controlled (conventional): volume-inconstant; pressure-controlled BIPAP: pressure-controlled, but with freedom to breathe spontaneously.

Volume-constant ventilation: Stress due to uneven gas distribution

Volume-constant ventilation provides constant ventilation even if lung mechanics change. The Evita ventilator ensures the delivery of a constant flow, and a time profile and tidal volume which are fixed.

Volume-constant ventilation is seen as particularly useful when ventilating an intact lung primarily to reduce the CO_2 concentration.

Ventilation involving a constant tidal volume and constant flow may, however, lead to local mechanical stress if the inspired gas is not distributed in the lung at a uniform rate, and problems of this kind have been reported in diseased lungs.

The two-compartment model in Figure 7 shows that gas distribution problems can be caused, for example, by localized increases in resistance. If a tidal volume with a constant high flow rate is administered in these circumstances, the compartment with the lower resistance will be inflated first.

Differences in ventilation may cause a variety of mechanical stresses in the pulmonary tissue. Apart from temporary over-inflation of the compartment with low resistance and a difference in pressure between the two compartments, local shear forces may occur between the compartments.

This mechanical stress can produce local tissue damage, which if allowed to continue, can lead to acute pulmonary failure.

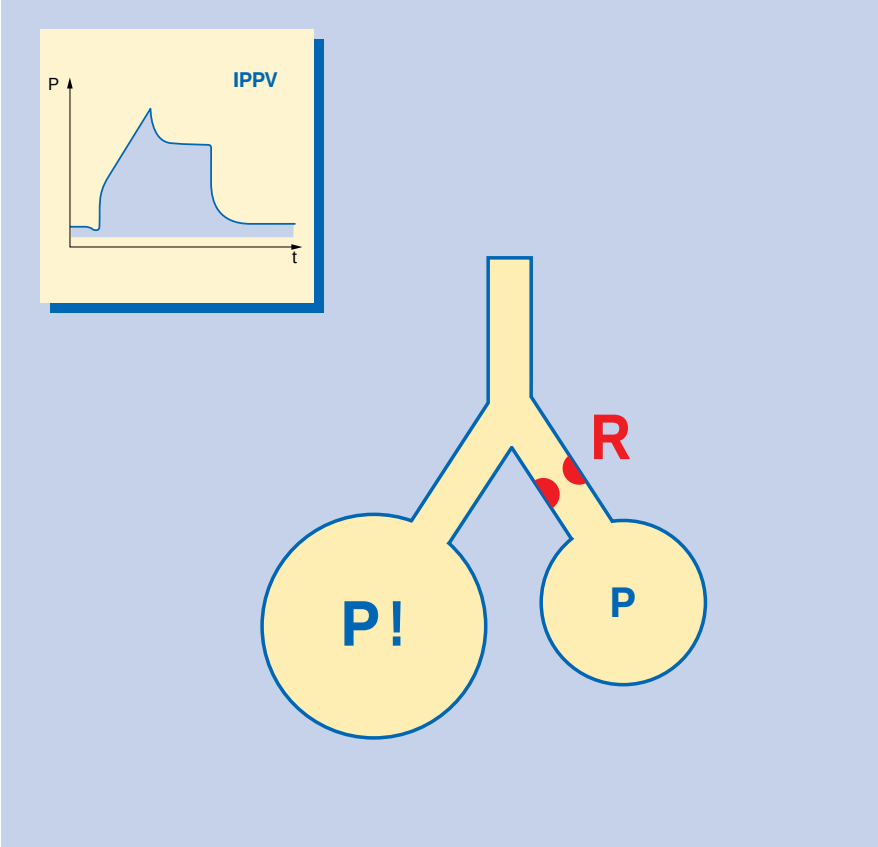

Fig. 7: Two-compartment model illustrating effects of volume-controlled ventilation.

The increased airway resistance (R) in the right compartment results in faster inflation and over-distention of the left compartment. Pressure (P) differences and different inflation volumes between the compartments produce severe mechanical stress.

Pressure-limited ventilation: An »intelligent« decelerating flow

Even when a patient's lungs are healthy, ventilation therapy produces changes in lung mechanics. Resistance may increase and compliance decrease during lengthy treatment. Unfortunately, these mechanical changes may not be distributed uniformly over the lung.

With a two compartment model it can be illustrated how negative effects of volume-constant long-term ventilation can be minimized by using pressure-limited ventilation where the airway pressure is limited by the maximum pressure (P_{max}) set.

With pressure-limited ventilation the tidal volume is always applied but the flow only reaches the value set by the operator at the start of the mechanical breath. As soon as the airway pressure reaches the P_{max} value, the Evita ventilator automatically reduces the flow (decelerating flow). Figure 8 shows the change of airway pressure with time.

A major advantage of pressure-limited ventilation with the Evita ventilator is that the flow adapts continuously to changes in lung mechanics. The Evita ventilator does not produce a fixed decelerating flow but determines the optimum flow profile for every single breath when administering the tidal volume required. The set pressure limit is not exceeded and tidal volume is applied as quickly as possible.

The extent to which the flow profile is being affected by lung mechanics is easily seen on the Evita ventilator's screen. If, for example, resistance is reduced following bronchial suction, a distinct change in the flow waveform is apparent.

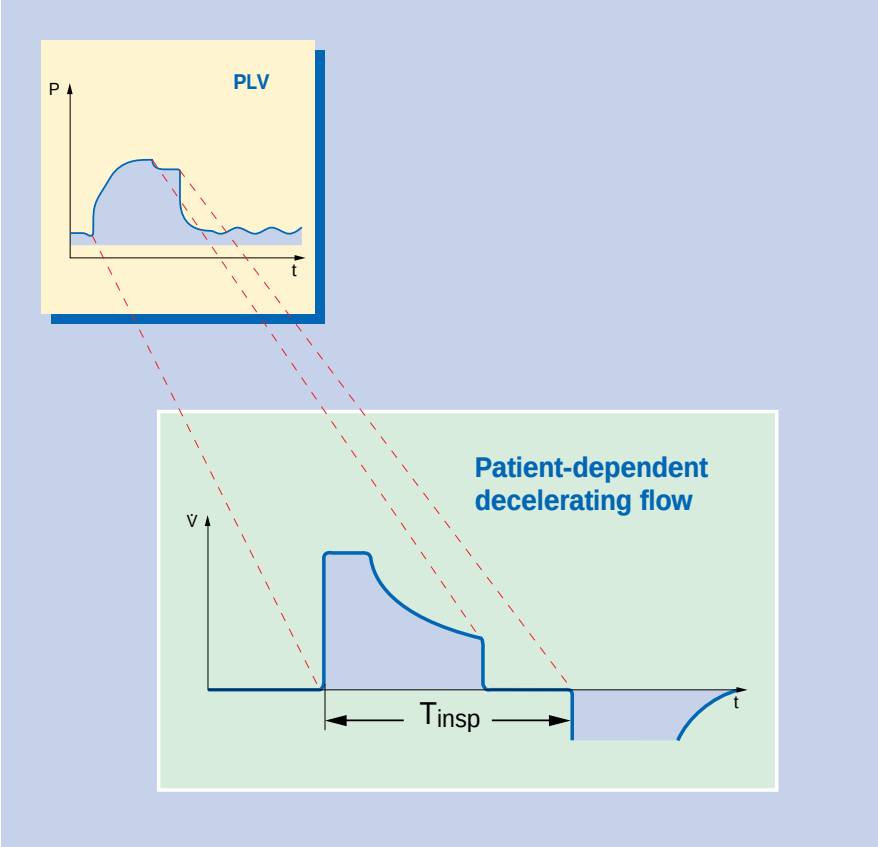

Fig. 8: Variation in pressure and flow with time during pressure-limited ventilation.

A set constant flow is generated in the first phase. As soon as the set maximum airway pressure is reached, the Evita ventilator reduces the flow progressively (decelerating flow). The ventilator terminates the flow once the set tidal volume has been completely administered.

Pressure-controlled ventilation: Everything under control?

The ventilation of a diseased lung is something of a balancing act. On the one hand, adequate ventilation needs to be maintained at an acceptable inspiratory pressure. However, on the other hand, the peak pressure must be kept as low as possible to avoid further deterioration in a lung disorder.

As lung mechanics worsen progressively, a choice between these two alternatives becomes inevitable. If, for example, ventilation is maintained at a constant tidal volume, pressure will increase automatically giving a reduction in compliance. If, on the other hand, a constant ventilation pressure is applied in these conditions, i.e. pressure-controlled ventilation is employed, there is a risk of under-ventilation.

The choice is a matter for the clinician. The following explanations show the effect of conventional pressure-controlled ventilation.

Figure 9 illustrates the disadvantage of standard pressure-controlled ventilation very clearly – the patient is not able to exhale during the mandatory breath! Expiratory efforts produce an increase in pressure – the patient has to be sedated or relaxed.

In conventional pressure-controlled ventilation the pressure is only really under control under certain conditions. When a patient's ability to breathe spontaneously increases, the limits of conventional pressure-controlled ventilation are soon reached.

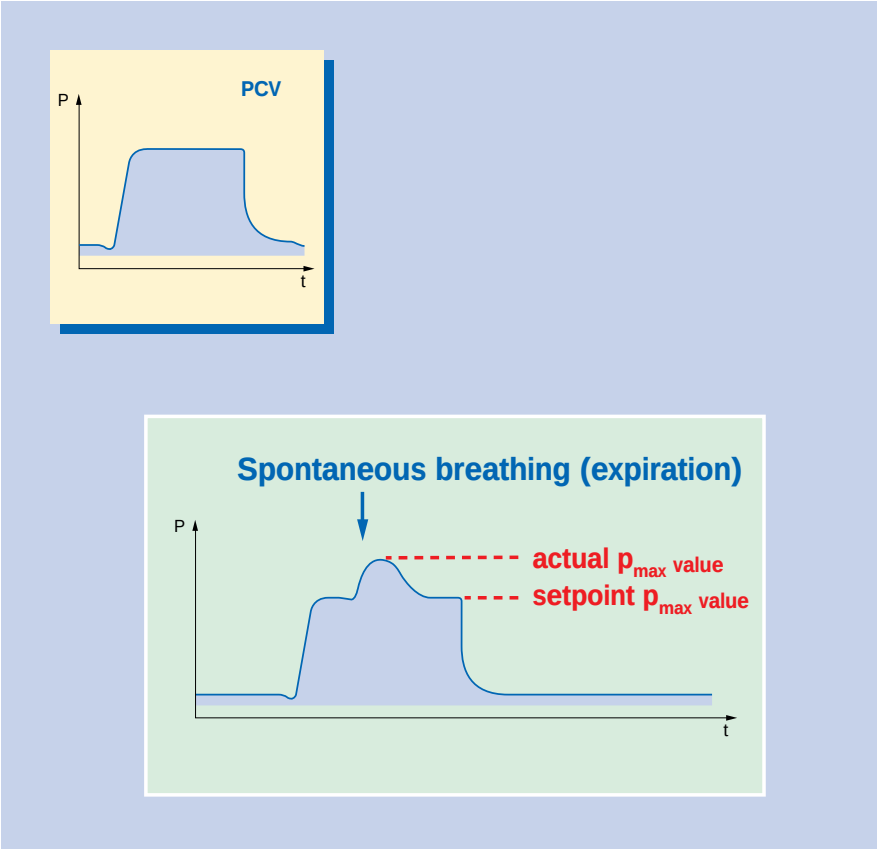

Fig. 9: Variation in pressure with time during conventional pressure-controlled ventilation.

Spontaneous breathing is superimposed on the mechanical breaths. Since exhalation is not possible during the mandatory breath, the patient's expiratory efforts increase the airway pressure above the set maximum level (P_{max}).

BIPAP:
Pressure-controlled at last!

In contrast to conventional pressure-controlled ventilation, spontaneous breathing with BIPAP does not necessarily lead to the sort of complications that have already been described. Instead, the patient's independent breathing can be of therapeutic value.

The possibility of spontaneous breathing at all times is less stressful for many patients. The willingness to undertake more of the ventilation effort is increased and the weaning process accelerated.

BIPAP both increases the patient's motivation to breathe spontaneously and the ability to do so. If spontaneous breathing can take place at any time there is less need for sedation, since inspiratory efforts do not have to be suppressed with sedatives. It may then be possible to reduce the degree of intervention in ventilation still further.

BIPAP represents progress in terms of individually adapted ventilation. Figure 10 illustrates the principle on which BIPAP works.

When conventional ventilation techniques are used the expiratory valve remains closed during a mandatory breath. The valve will only open under very high airway pressure e.g. during coughing. In this case, however, the inspiration phase is terminated instantly.

With BIPAP ventilation using the Evita ventilator, the expiratory valve reacts to even a slight increase in airway pressure. A sensitive control mechanism allows the inspiratory valve to provide exactly the right amount of breathing gas to maintain a constant airway pressure.

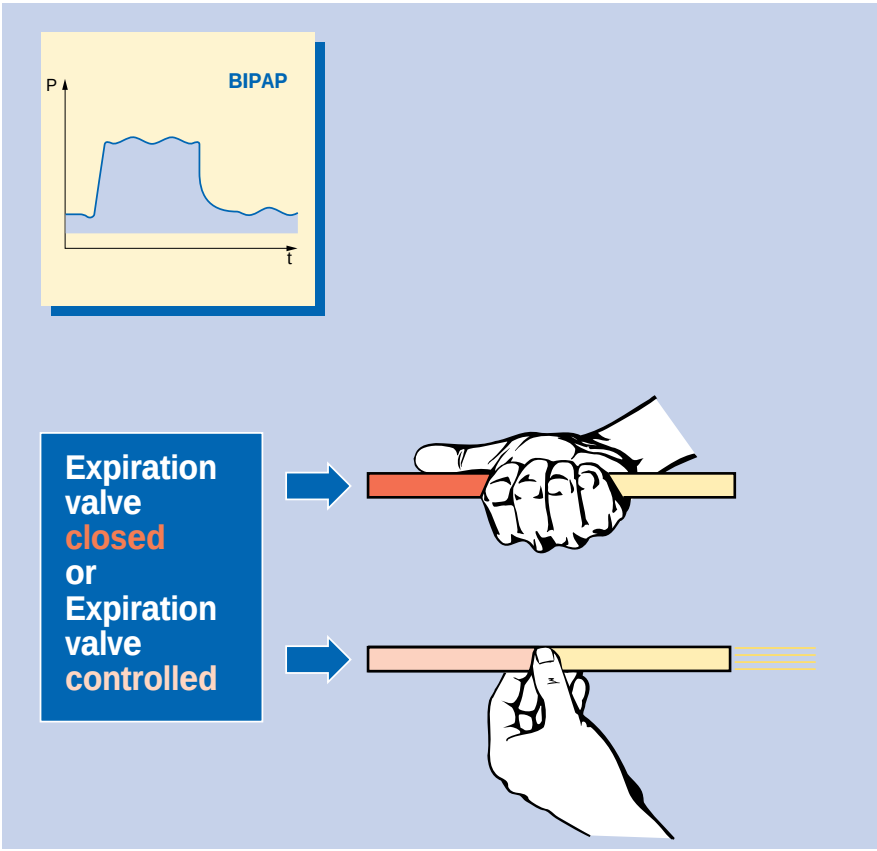

Fig. 10: The BIPAP technique: Regulation of expiratory valve.

In conventional pressure-controlled ventilation, the ventilator keeps the expiratory valve tightly closed like a firm hand sealing off a hose. With BIPAP the expiratory valve is sensitively controlled by the Evita ventilator like a gentle hand carefully controlling the flow in a hose in time with the patient's spontaneous breathing.

BIPAP in clinical practice: Implementation into the Evita concept

A ventilator which has a clearly defined set of operating principles is simpler to use than one which is inconsistent. It is also much easier to learn new ventilation modes when they relate clearly to those which already exist.

The Evita ventilator already has easy-to-learn setting of conventional ventilation parameters. The transition from volume-constant ventilation to pressure-limited, and then pressure-controlled ventilation is flexible and does not require any switching between modes.

BIPAP ventilation with the Evita 2 ventilator has developed these principles still further. The parameters which have to be adjusted for ventilation pressure and PEEP are similar to those for conventional ventilation and, with the Evita 2 ventilator, the time pattern is set in exactly the same way for both BIPAP and conventional ventilation.

The first studies on BIPAP were published long after the Evita ventilator was developed and established. Nevertheless, the BIPAP ventilation mode was rapidly incorporated into Evita without any major changes to the electronics and pneumatics.

The fact that it was possible to introduce a ventilation mode with the Evita ventilator which did not even exist when the machine was first developed, is ample proof that its design was future orientated.

Evita 2

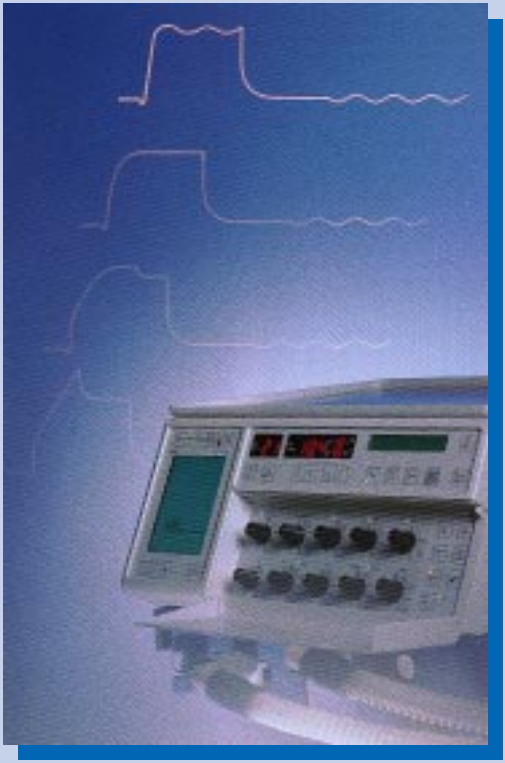

Fig. 11: BIPAP and conventional ventilation – operating with the same parameters.

In operation, the Evita 2 can be switched easily between volume-constant, pressure-limited, conventional pressure-controlled ventilation and BIPAP. The parameters for setting BIPAP are almost identical to those for conventional ventilation.

Pressure-supported ventilation: Reducing the patient workload

Pressure-supported ventilation is another form of augmented ventilation. Both the degree of mechanical assistance and the time profile for the separate breaths are governed by the patient's requirements and are, therefore, not specified by the clinician. Pressure-supported ventilation enhances the spontaneous breathing element in ventilation to the full. It is thus a weaning mode in the classical sense.

On the Evita ventilator, pressure-supported ventilation is available in the ASB mode (Assisted Spontaneous Breathing).

The quality of pressure-supported, spontaneous breathing essentially depends on how well machine support is synchronized with the patient's spontaneous breathing.

The rate of delivery of pressure support can be adjusted according to the breathing drive and lung mechanics of the patient. Under certain conditions such as a high respiratory rate, conventional pressure-supported ventilation may not be accurately synchronized with the patient's spontaneous breathing effort. Pressure-supported ventilation, which is designed to assist all spontaneous breathing activity, may not therefore be the best option in every case.

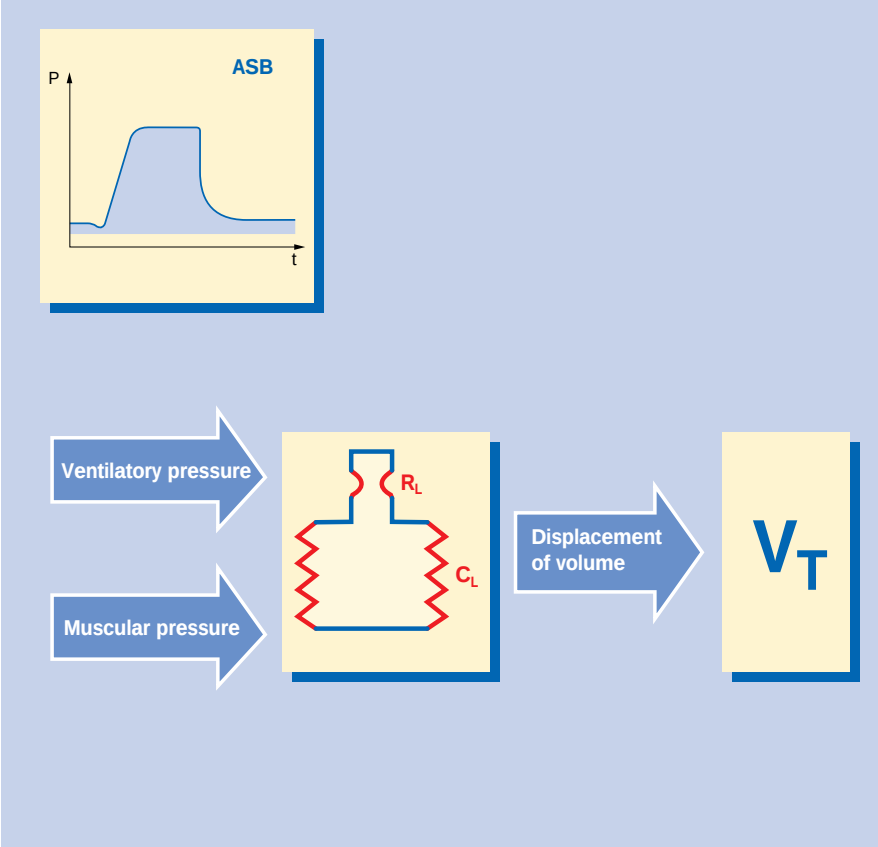

Fig. 12: Conditions of pressure-supported ventilation.

Once pressure support has been triggered, ventilation pressure and muscular effort act on the lung, whose mechanical properties are governed by its compliance (C_L) and resistance (R_L). The result is a change in volume of limited duration, which delivers the tidal volume (V_T). The extent of the change in volume is essentially determined by the lung mechanics.

Synchronization in BIPAP: Flexible time control

In contrast to pressure-supported spontaneous breathing, BIPAP makes no attempt to provide assistance for all the patient's spontaneous breathing activity. BIPAP specifies time segments in which the patient can breathe as much and as often as necessary at two different CPAP levels. The change in pressure from the lower CPAP level to the upper pressure level is the ventilator's contribution to ventilation and this produces a flow.

The changes in pressure are triggered by the patient's spontaneous breathing. The operator does not set fixed phases of machine support but rather only approximate values. As a result, the actual length of time at the CPAP level can vary within defined limits, but the frequency of mechanical breaths remains constant over time (»smooth« time control).

The Evita ventilator has a flow trigger which is similar to that for pressure-supported spontaneous breathing. The sensitivity of the trigger can be adjusted to suppress artifacts. Switching from the upper CPAP level to the lower level is synchronized with the patient's breathing and triggered by expiratory activity in a similar way.

The pressure changes are governed by time segments (trigger windows) in which Evita synchronizes with the patient's spontaneous breathing. If there is no spontaneous breathing within the time window, Evita switches to the new pressure level at the end of the time window without being triggered.

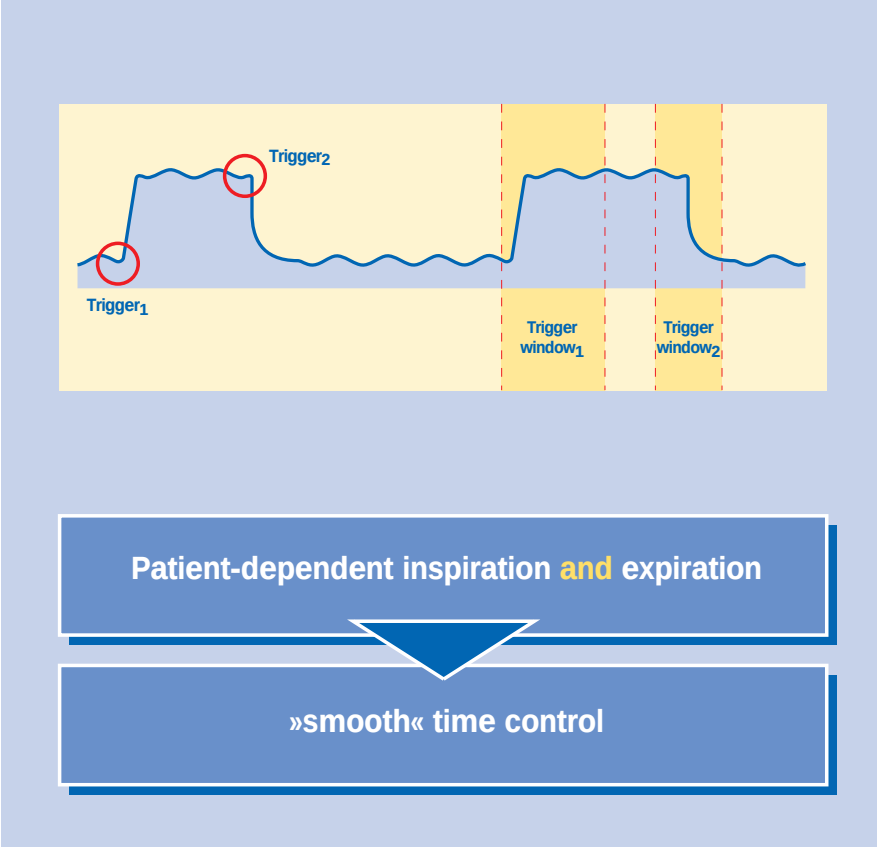

Fig. 13: Synchronization of spontaneous breathing and mechanical ventilation with BIPAP.

The change in pressure from lower to upper pressure levels is initiated by a flow trigger in a similar manner to pressure-supported ventilation. The change from upper to lower levels takes place when the patient begins to exhale and inspiratory flow has dropped to zero. Both changes are therefore synchronized with the patient's breathing.

Advantages for the patient: Control and support optimized

The principles by which BIPAP operates tackle two basic problems of conventional ventilation: the suppression of spontaneous breathing during mechanical ventilation and inadequate synchronization of mechanical ventilation with the patient's spontaneous breathing.

Spontaneous breathing during mechanical ventilation allows additional volumes to be ventilated. This allows the levels of mechanical ventilation and overall intervention to be reduced.

In addition, it is less stressful for patients to be able to breathe spontaneously at any time. The need for sedatives may also be reduced.

Computer simulations demonstrate how much more effectively mechanical ventilation is adapted to spontaneous breathing when »smooth« BIPAP time cycling is used.

BIPAP accepts the patient's spontaneous breathing rate and synchronizes machine support with these inspiratory and expiratory efforts. However, in contrast to conventional pressure-supported ventilation, BIPAP makes no attempt to provide pressure support for each spontaneous effort.

The advantages of BIPAP for the patient have been described in the first two sections of this guide where this new ventilation mode is compared with conventional ventilation. The following sections deal with the clinical application of BIPAP and assess the benefits for hospital staff.

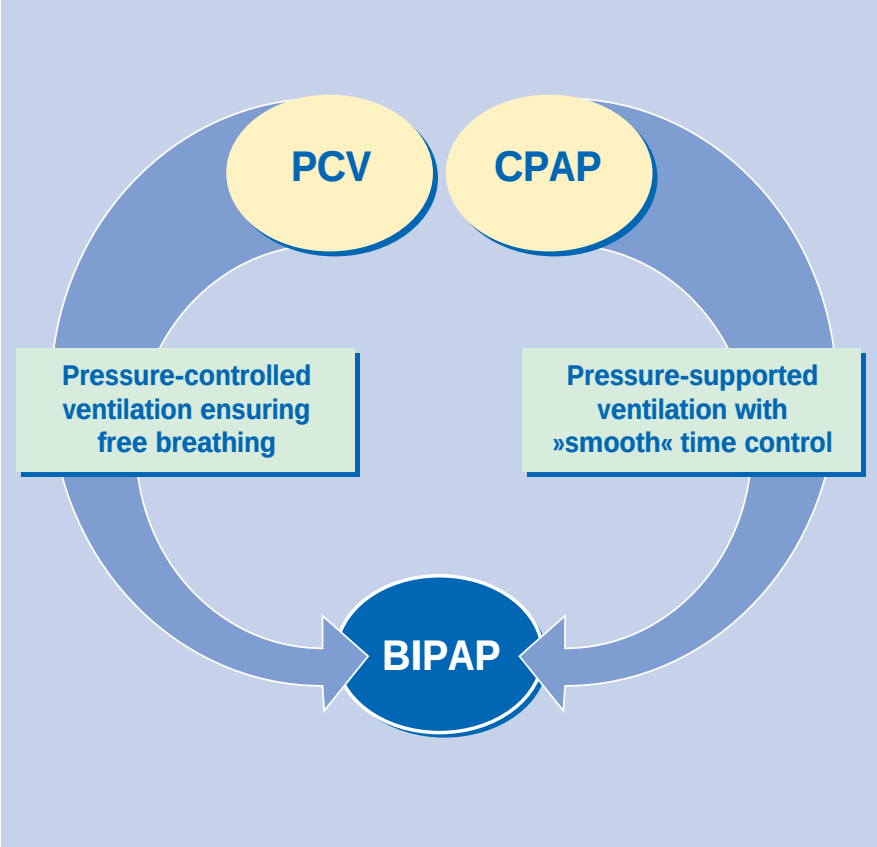

Fig. 14: BIPAP compared with pressure-controlled and pressure-supported ventilation.

The freedom to breathe during pressure-controlled ventilation allows additional gas exchange to occur. Flexible time cycling allows inspiratory and expiratory times to be matched to the patient's spontaneous breathing.

BIPAP in the early stages: Corresponding parameters

Even in the first BIPAP studies it was clear that the new ventilation concept was more than a breakthrough for the patient, it also had several advantages for users. Figure 15 shows the original adjustable BIPAP parameters on the Evita 1 ventilator compared to IPPV.

The basic BIPAP setting only involved four parameters: the pressure parameters, P_{high} and P_{low} and the time parameters, T_{high} and T_{low}. Thus the basic operating settings appeared to be quite simple.

As regards the pressure parameters, the lower value was set directly as P_{low}, in much the same way as PEEP in conventional ventilation. There were, however, fundamental differences in terms of the upper pressure value. With BIPAP, the user set this value directly as P_{high}. The corresponding pressure for IPPV is plateau pressure, P_{plat}, which is derived from the set tidal volume as a function of the patient's lung mechanics.

With BIPAP, the times for inspiration and expiration were set directly as time parameters by entering the time values, T_{high} and T_{low}. For IPPV this is done indirectly by way of the adjustable parameters, rate (f) and I:E ratio.

Despite its simplicity, many users still found the original BIPAP four-parameter setting unusual when it was first introduced. Therefore in the Evita 2 ventilator, this form of setting was only made available in the special BIPAP-APRV version. In the standard version, BIPAP setting was incorporated alongside conventional modes.

With the introduction of the Evita 2 ventilator, BIPAP entered the second generation.

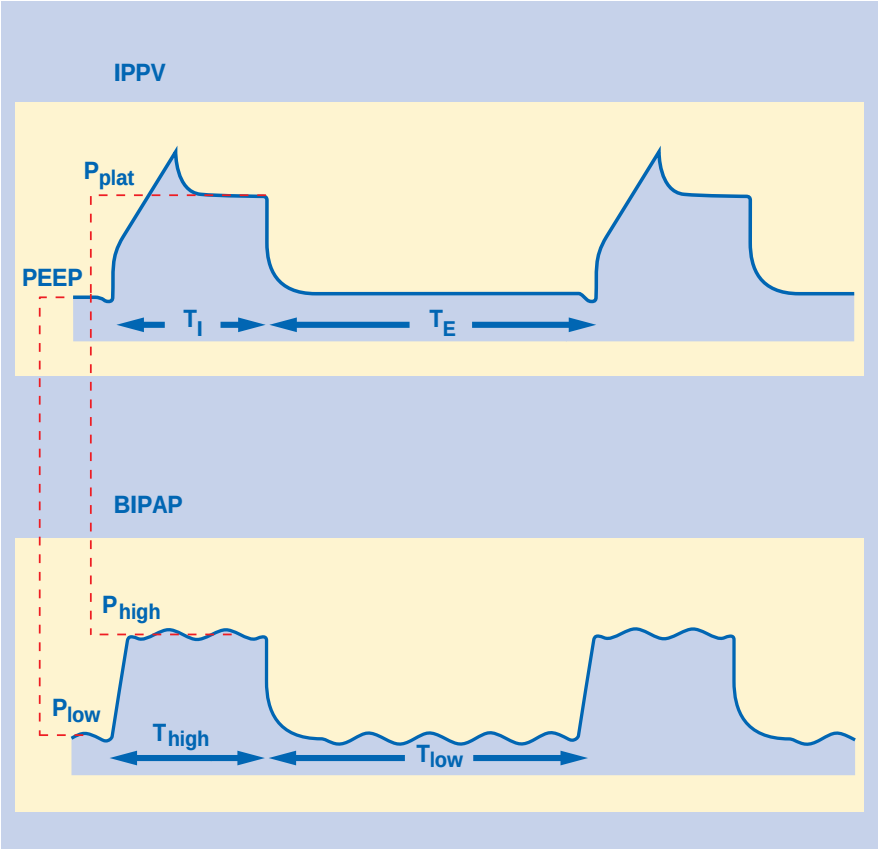

Fig. 15: Parameter settings in IPPV and BIPAP with the Evita 1 ventilator.

P_{low} in BIPAP corresponds to PEEP in IPPV and the P_{high} in BIPAP corresponds to P_{plat} in IPPV. With BIPAP, the values for inspiratory and expiratory time are set as T_{high} and T_{low}, whereas in IPPV they result from the settings for rate (f) and I:E ratio.

BIPAP in its second generation: A new concept of operation

Before the Evita 2 ventilator was introduced, five years had been spent analysing experience with the use of BIPAP in Evita ventilation. The results of this work were new operating principles and improvements of BIPAP with Evita 2 which are listed below.

1. BIPAP can be directly selected by pressing a knob, no longer only via menu.

2. BIPAP is operated in a similar manner to conventional ventilation, with the time pattern and PEEP being set in exactly the same way.

3. The time profile for adjusting the pressure gradient in a BIPAP breath can be modified by the user.

4. In the special BIPAP-SIMV mode, BIPAP ventilation can be combined with conventional pressure-supported ventilation.

5. The new Evita 2 expiratory valve is particularly adapted to the specific requirements of BIPAP ventilation.

There are two important advantages in making BIPAP and conventional ventilation modes similar to use: learning how to set the parameters is a quicker process and changes from conventional ventilation become easier in everyday use. Figure 16 illustrates the common operating parameters for conventional ventilation and for the second generation of BIPAP.

The extra possibility of adjusting the pressure gradient enables the start of pressure support to be geared to the patient's needs, as with ASB. The addition of BIPAP-SIMV means that BIPAP breaths can be combined with conventional, pressure-supported spontaneous breathing. This mode is of particular interest to those who wish to take advantage of the reduced intervention of BIPAP breaths, but still want to proceed along conventional SIMV lines for weaning.

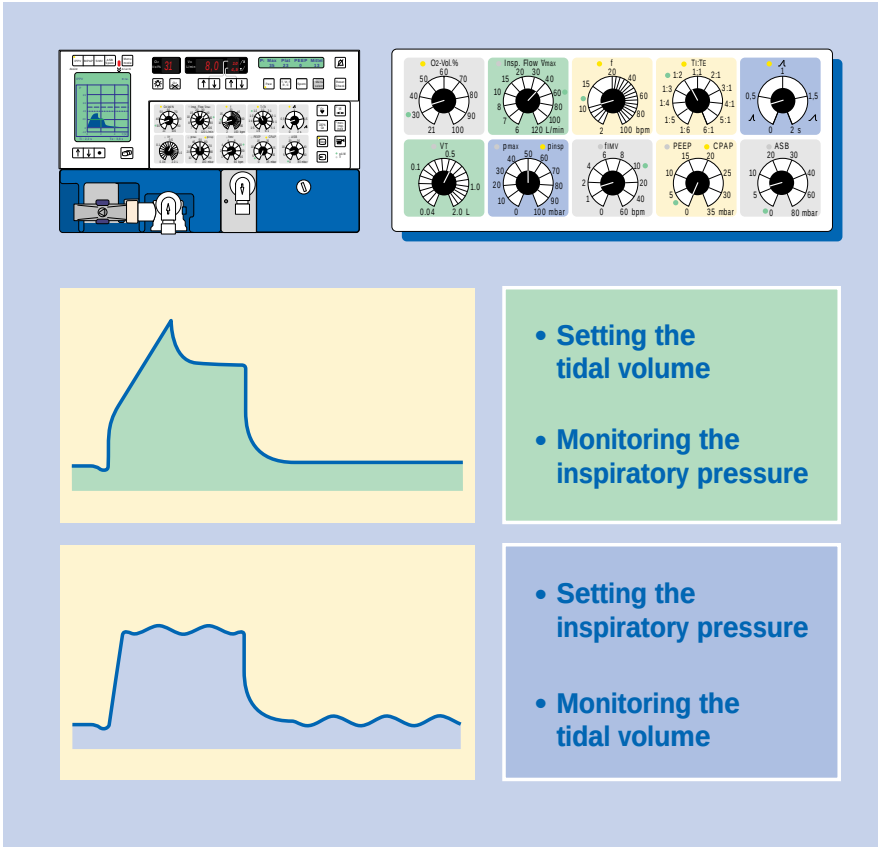
• Setting the tidal volume
• Monitoring the inspiratory pressure
• Setting the inspiratory pressure
• Monitoring the tidal volume

Fig. 16: Parameter settings in IPPV and BIPAP with the Evita 2 ventilator.

The colours used on the control panel of the Evita 2 ventilator (shown in the top right of the illustration) and in the two waveforms indicate the parameters relevant for the setting of the two ventilation modes. The settings for rate (f), I:E ratio and PEEP are the same in both modes. In IPPV, mechanical breaths are set by the tidal volume ($\dot{V}_t$) and the breathing gas flow ($\dot{V}$), whereas with BIPAP it is ventilation pressure (P_{insp}) and the pressure gradient (, ramp) which are set.

Getting used to BIPAP: New methods step by step

The first sections of this introductory guide compared the therapeutic effects and operating principles of BIPAP with those of conventional ventilation. This section describes the process of learning how to use BIPAP for ventilation and weaning with both the Evita 1 and Evita 2 ventilators.

BIPAP treatment can follow IPPV ventilation or be initiated immediately after the patient has been connected. Recommended settings have been published [5] for both these situations and are summarized in Figure 17.

When switching from volume-constant ventilation the time setting does not have to be changed for BIPAP ventilation. This is particularly easy with the Evita 2, as time values are set in the same way for IPPV and for BIPAP. With the Evita 1 ventilator, switching to BIPAP involves calculating the values for T_{high} and T_{low} from the respiratory rate and I:E ratio values of the IPPV setting.

As regards the pressure parameters, the lower pressure value (P_{low}) is identical to the PEEP from the IPPV setting. Here again the Evita 2 takes the value from the IPPV setting automatically, whereas P_{low} had to be set specifically on Evita 1. The ventilation pressure (P_{insp}) (corresponding to P_{high} on Evita 1) is governed by the plateau pressure as measured in IPPV. Before switching from IPPV to BIPAP, P_{max} should be reduced to at least the plateau value for pressure. After switching, the tidal volume should be monitored carefully so that ventilation pressure can be adjusted if deviations from the set point occur.

If BIPAP is used from the very beginning of ventilation, a ventilation pressure of 12-15 mbar above PEEP [5] is recommended in the relevant literature. The tidal volume should then be noted and P_{insp} adjusted if necessary. All other adjustable parameters are derived from those of conventional ventilation, as described above.

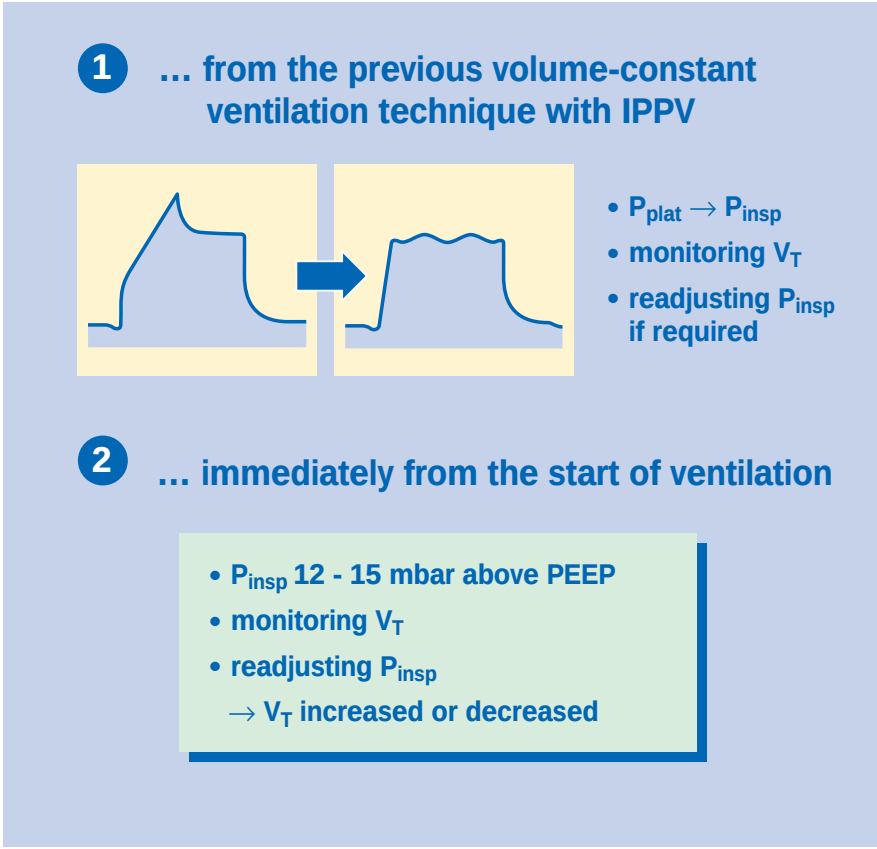
1
… from the previous volume-constant ventilation technique with IPPV
• $P_{plat} \rightarrow P_{insp}$
• monitoring V_T
• readjusting P_{insp} if required
2
… immediately from the start of ventilation
• P_{insp} 12 - 15 mbar above PEEP
• monitoring V_T
• readjusting P_{insp}
→ V_T increased or decreased

Fig. 17: Starting ventilation with BIPAP according to Hörmann et al. [5].

1) When switching from IPPV ventilation, the plateau pressure serves as a guideline for setting the ventilation pressure (P_{insp}). The tidal volume (V_T) is noted and altered, if necessary, by adjusting the ventilation pressure (P_{insp}).

2) To start BIPAP ventilation when there has been no previous IPPV ventilation, the authors recommend a P_{insp} setting of 12-15 mbar with subsequent observation of V_T and, if necessary, adjustment of P_{insp}.

Principles of ventilation with BIPAP: A gas exchange model

According to the relevant literature, the conditions of gas exchange [4] and the treatment of ventilation/oxygenation problems when using BIPAP [5] are as follows.

Gas exchange in the lungs may be impaired for various reasons, such as impaired respiratory mechanics, inadequate ventilation of sections within the lung or poor blood circulation. Figure 18 shows these causes in diagramatic form.

The left and right alveoli in the diagram illustrate the two types of problems within the lung and their effects on the ventilation/circulation ratio $\dot{V}_A/\dot{Q}$ Firstly, alveoli may be cut off from ventilation (due to collapsed alveoli for example) and there may be no oxygenation of the blood ($\dot{V}_A/\dot{Q} = 0$) despite good circulation. Secondly, intact alveoli can be cut off from the blood supply by embolism, for example, so that, in spite of good ventilation, there is no gas exchange and thus merely dead-space ventilation ($\dot{V}_A/\dot{Q} = \infty$). Various intermediate states are also possible.

When treating the problems of gas exchange, a distinction has to be made between oxygenation problems and impairment of ventilation. Oxygenation can be improved, firstly, by enlarging the surface available for gas exchange with a higher CPAP or PEEP and, secondly, by increasing the inspiratory oxygen concentration. Enhanced ventilation (for example, when respiratory mechanics are impaired), can only be achieved by mechanical ventilation which produces an active flow.

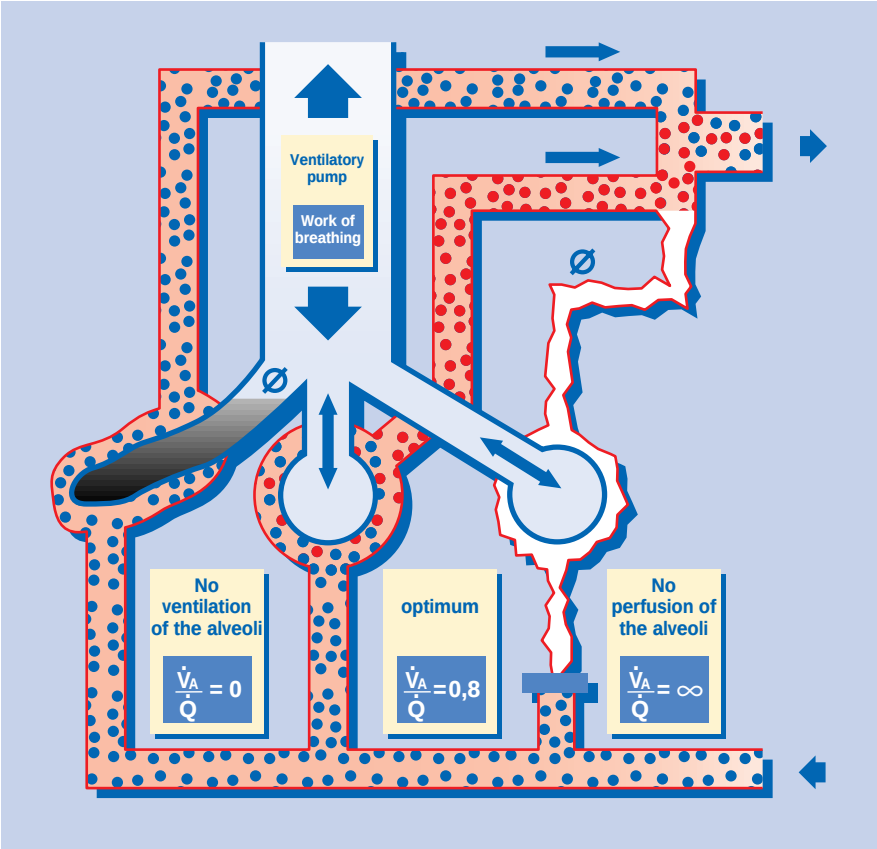

Fig. 18: Three-compartment model for gas exchange.

The model illustrates how respiratory mechanics operate under ideal conditions and also shows two extreme examples of pulmonary gas exchange. Under ideal conditions, alveolar ventilation and circulation are optimal and the ventilation/circulation ratio ($\dot{V}_A/\dot{Q}$) is 0.8. In extreme cases, the alveoli are not ventilated ($\dot{V}_A/\dot{Q} = 0$) or not supplied with blood ($\dot{V}_A/\dot{Q} = \infty$). The colour of the erythrocytes indicates the result of gas exchange, red: good oxygenation, blue: poor oxygenation.

Principles of ventilation with BIPAP: Keeping the lung open

Ventilation should be used to treat respiratory disorders as selectively as possible. Criteria for the application and administration of specific procedures in conventional ventilation can be taken from basic literature [2][6]. Now BIPAP also offers several different ventilation strategies. Recent studies describe the selective treatment of oxygenation and ventilation problems in detail [5].

The primary aim in treating oxygenation problems is to restore the surface available for gas exchange, in order to keep the functional residual capacity stable at an optimum value. With this the most favourable circumstances will be provided for gas exchange, for the optimal ventilation/circulation ratio and for the work of breathing. Frequently, inspiratory oxygen concentration has to be increased additionally.

If the functional residual capacity is reduced the likelihood of the endexpiratory collapse of the alveoli increases. This may cause tissue damage.

The treatment of oxygenation problems with BIPAP is illustrated in Figure 19 with the functional residual capacity being adjusted as necessary by increasing the mean airway pressure. The measures taken are as follows:

1) Parallel increase of the lower and upper values of pressure. On the Evita 2 ventilator, PEEP and P_{insp} are increased by the same amount.

2) Lengthening/shortening of the times at the upper and lower pressures. For the Evita 2 ventilator a change in I:E ratio is required.

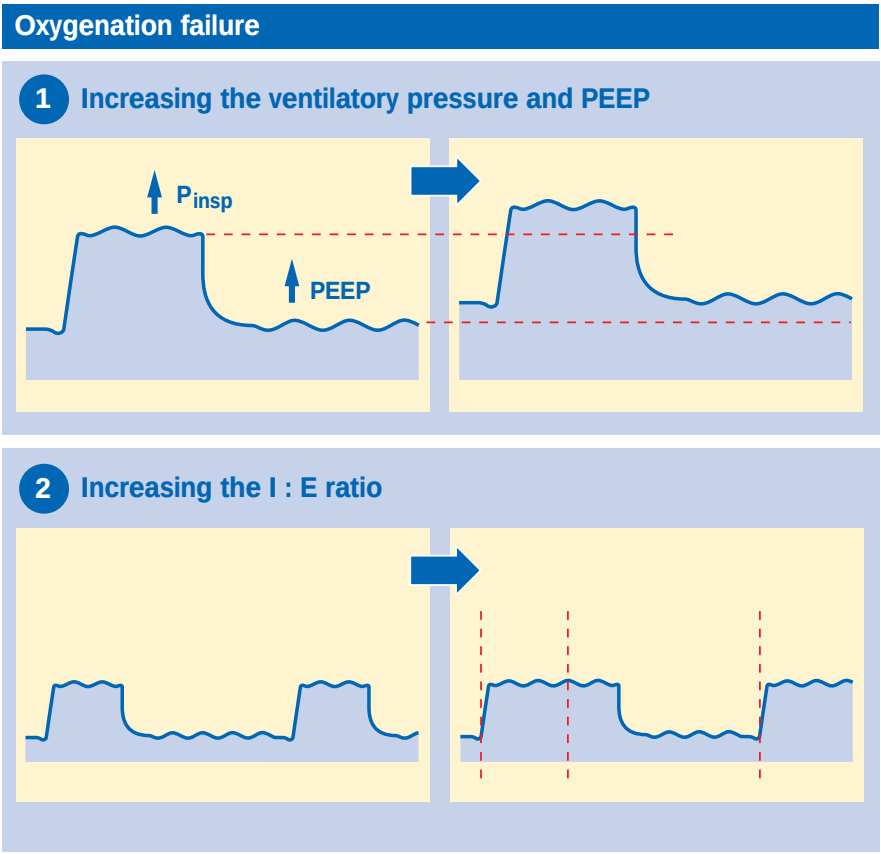

Fig. 19: Treatment of oxygenation problems with BIPAP.

The mean airway pressure can be increased in two ways to enhance the functional residual capacity (FRC):

1) Parallel increase in ventilation pressure (P_{insp}) and PEEP

2) Increase in I:E ratio

Principles of ventilation with BIPAP: Opening up the lung

When ventilation problems are being treated, the ventilator reduces the patient's work of breathing. It produces an intermittent airway pressure to a specified time pattern and thus produces a flow in the lung.

The patient's own breathing is also important, as ventilation which is properly adjusted to spontaneous breathing reduces the extent to which the patient »fights against« the ventilator. Good synchronization of ventilation and spontaneous breathing means lower oxygen consumption, less sedation, and, possibly, no need for relaxants.

When treating ventilation problems with BIPAP there are no restrictions on natural breathing and, therefore, there is better co-ordination between mandatory ventilation and the patient's breathing.

Examples of ventilation settings are given in Figure 20. The measures to increase ventilation whilst maintaining the same mean pressure are as follows:

1) Increase ventilation pressure by altering lower and upper pressure in opposite directions – with the Evita 2 ventilator these parameters are PEEP and P_{insp}.

2) Shorten the T_{low} and T_{high} times – with the Evita 2 ventilator the respiratory rate is increased.

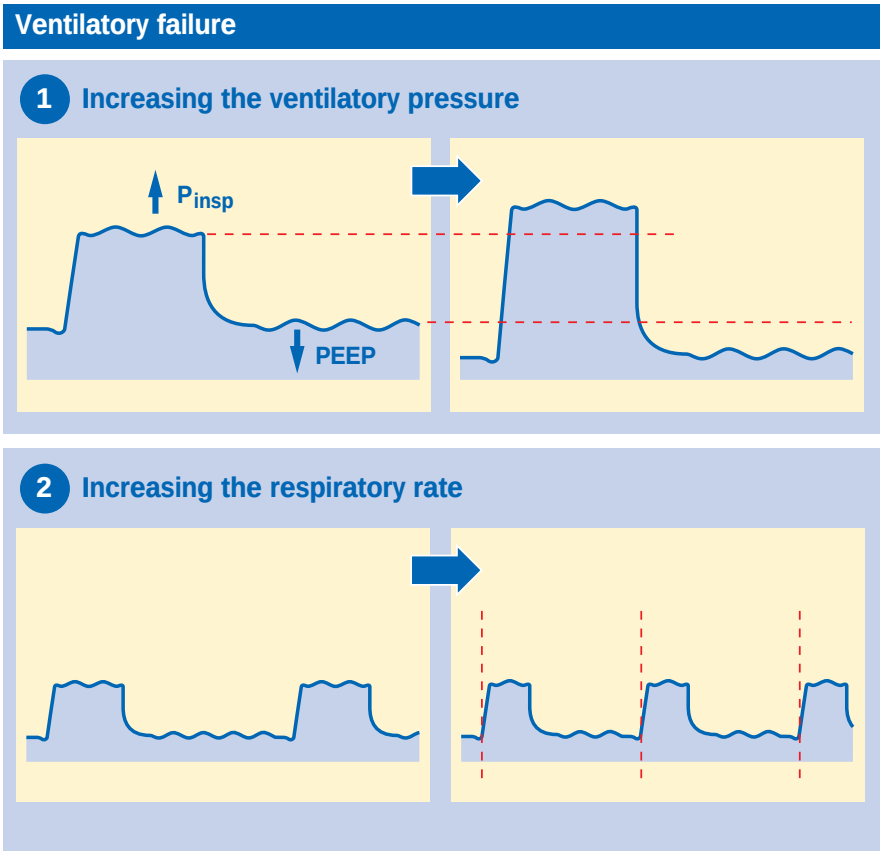

Fig. 20: Treatment of ventilation problems with BIPAP.

An increase in ventilation, whilst maintaining the same mean airway pressure, is achieved in two ways

1) An increase in upper pressure value and a decrease in lower pressure value by an equal amount

2) An increase in respiratory rate

Recurring spontaneous breathing: Breathing allowed!

Ventilation produces therapeutic effects, but it also has various side effects on the lungs and other organs.

An increase in the degree of intervention is generally unavoidable if the condition of the lungs deteriorates. High ventilation pressures, high O_2 concentrations or lengthy ventilation therapy contribute to intervention. Ventilation modes which do not permit spontaneous breathing normally intervene to a higher degree than augmented modes.

Though there are no alternatives to the majority of measures involving deep intervention, there are seldom clinical grounds for suppressing spontaneous breathing.

When BIPAP is used, the patient's spontaneous breathing provides additional ventilation, so that the extent of mechanical ventilation can be reduced and ventilation pressures lowered. The possibility of permanent free spontaneous breathing may require less sedation.

A particular feature of spontaneous breathing is that it permits better ventilation of the lower (basal dorsal) areas of the lung. Thus spontaneous breathing causes a better ventilation of those sections of the lung for which mechanical ventilation could lead to an unacceptable level of intervention because of the high pressures and long inhalation times.

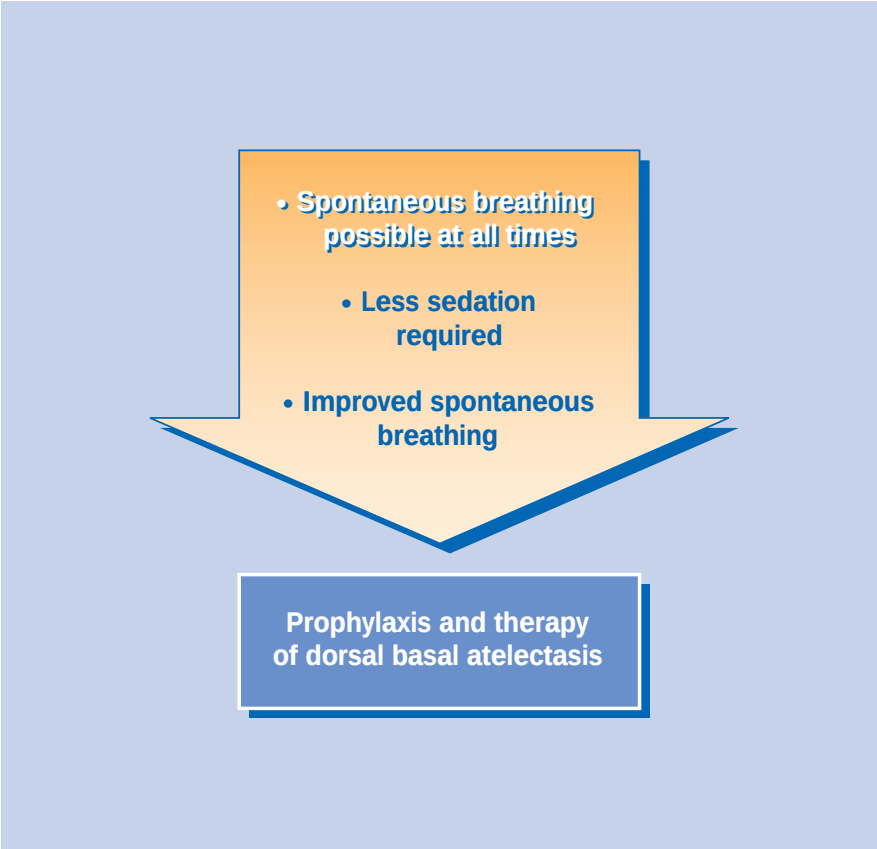
• Spontaneous breathing possible at all times
• Less sedation required
• Improved spontaneous breathing
Prophylaxis and therapy of dorsal basal atelectasis

Fig. 21: Breathing spontaneously – the positive effects.

The diagram shows the principle of a positive enhancement and the ongoing effects of unimpeded spontaneous breathing. A reduced use of sedatives enables spontaneous breathing to increase. The volume of spontaneous breathing is therefore increased and in particular dorsal basal atelectasis reduced.

Weaning with BIPAP (1): Beginning step by step...

Weaning is described in the medical literature [2] as the systematic reduction of respiratory support. Weaning is not so much a rigid procedure with an inflexible schedule, but rather a dynamic process. The measures taken must be constantly adapted to symptoms and progress monitored continuously.

In the weaning phase, intervention is gradually reduced from pure mechanical ventilation, via augmented ventilation modes, to spontaneous breathing without machine support. There may also be situations where intervention is temporarily stepped up, for example, by using pure mechanical ventilation during the night to enable the inspiratory muscles to recuperate.

Various weaning strategies are described in the relevant literature. The work of Baum and Benzer is quoted here [2] as an example.

Conventional weaning usually starts with a reduction in O_2 concentration to less than 50%. The next stage is to decrease the I:E ratio to 1:2. PEEP can then be gradually stepped down to 5-7 mbar. In conventional weaning, a switch is then made to augmented ventilation modes which permit spontaneous breathing.

BIPAP weaning differs in one crucial respect, in that spontaneous breathing is possible at any time (even during ventilation with a high degree of intervention such as inverse I:E ratio).

The next two illustrations outline the BIPAP weaning process when an Evita 2 ventilator is being used. A detailed description of the process is given on the next text page.

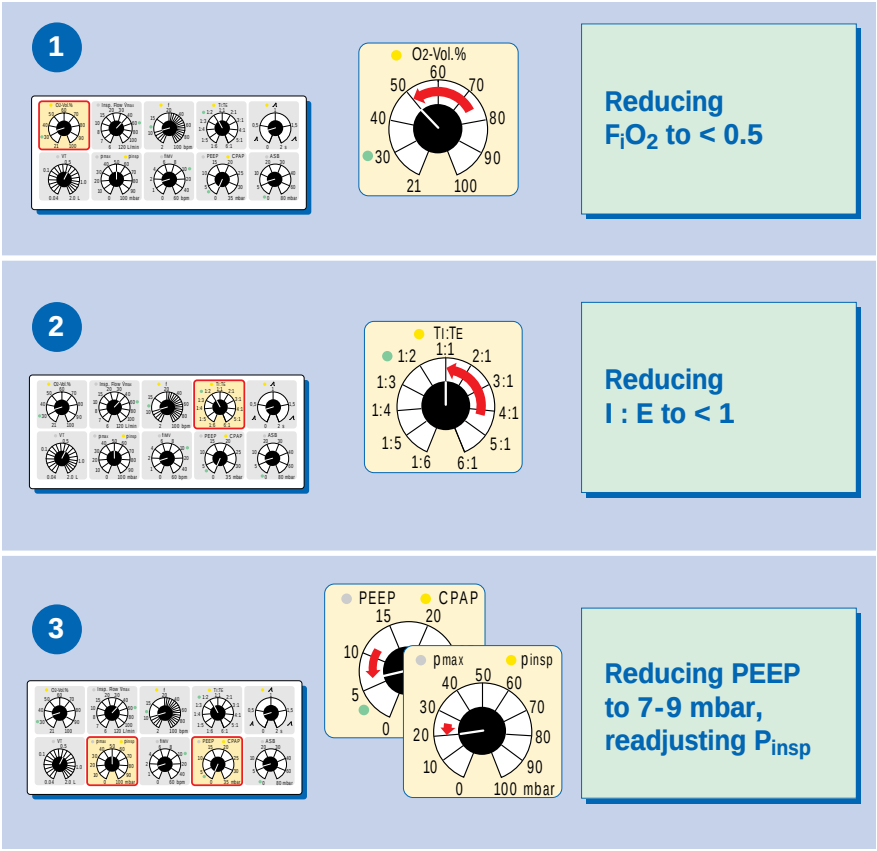

Fig. 22: Weaning procedures using BIPAP according to Hörmann et al. [5], part one.

1) Reduction of inspiratory O_2 concentration to less than 50%.

2) Reduction of I:E ratio until inspiratory time is shorter than expiratory time.

3) Gradual reduction of PEEP to 7-9 mbar with a parallel reduction in ventilation pressure.

Weaning with BIPAP (2): ... and keeping the procedure flexible

The BIPAP weaning procedure involves a gradual stepping down in the level of intervention just as conventional modes do. However, as the entire weaning process is conducted in one ventilation mode, weaning can be adapted more rapidly to suit the circumstances, as no decision has to be taken about changing modes.

Spontaneous breathing is possible throughout weaning because the BIPAP mode intervenes less than conventional ventilation does at comparable stages of weaning.

Weaning by the BIPAP method can be carried out on both the Evita 1 and the Evita 2 ventilators. Evita 1 and Evita 2 have different parameters, i.e. P_{low} = PEEP and P_{high} = P_{insp}. Hörmann et al. recommend the following phases for gradual weaning [5]. They are shown using the Evita 2 ventilator:

1. Reduction of inspiratory O_2 concentration to less than 50% (FiO_2 < 0.5).

2. Reduction of I:E ratio to 1:1 or less (I:E <1). Whilst doing this, the graphics screen should be observed to see whether the waveform for expiratory flow drops to 0. If there is still a residual flow at the end of the expiratory phase, there is residual pressure in the lung (intrinsic PEEP) and the I:E ratio may have to be reduced still further.

3. Gradual reduction of PEEP to 7-9 mbar and reduction of the upper value for pressure (P_{insp}) in parallel so as to decrease mean airway pressure.

4. Gradual reduction of ventilation pressure until the difference in pressure between PEEP and P_{insp} is 8-12 mbar.

5. Reduction of respiratory rate to 8-9 breaths per min initially (i.e. extension of pressure times to 3.5-4 s in each case) and then a further reduction of I:E ratio and rate.

6. Gradual matching of the two values for pressure to the mean airway pressure. Reduction of CPAP value only after the values for pressure have become identical.

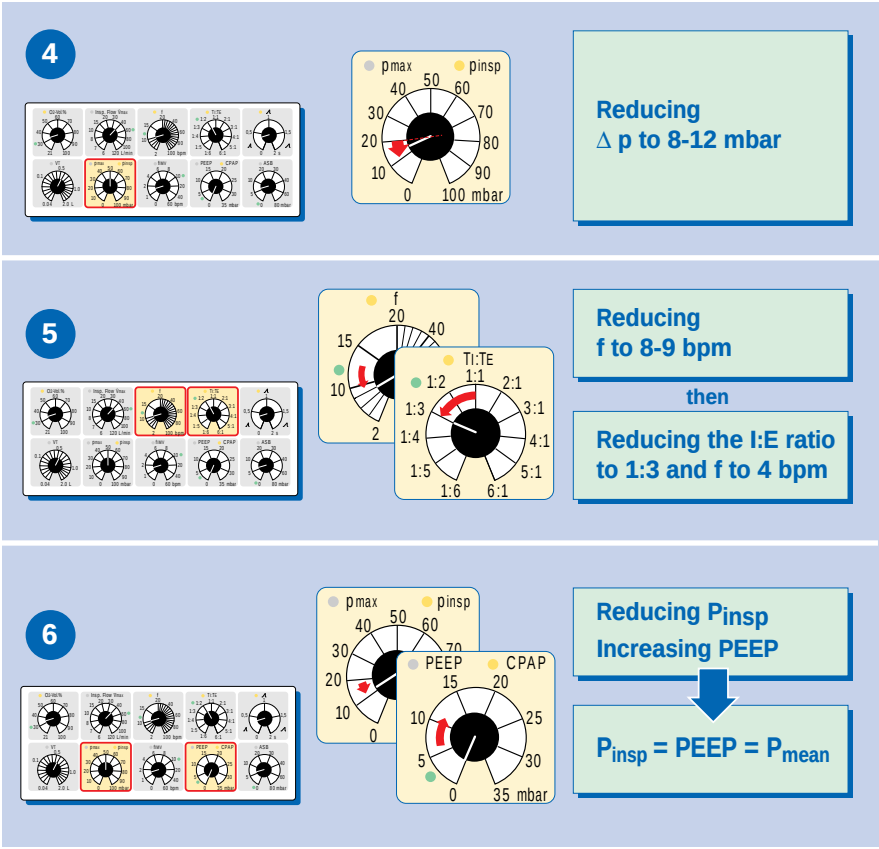

Fig. 23: Weaning procedures using BIPAP according to Hörmann et al. [5], part two.

The text explains the weaning stages (4) to (6). After stage (6) weaning follows the modes used in conventional ventilation.

Ventilation strategy with BIPAP: One mode for all applications

Medical literature contains various different strategies for ventilation and weaning. When a high level of intervention has continued throughout therapy, or even increased, this is termed »ventilation« in this section. A step-by-step approach is shown on the next page in which the measures taken are arranged on a scale according to their degree of intervention. Steps which lead to a reduction in the level of intervention are termed »weaning«.

Some basic rules apply to the use of the step-by-step approach. Respiratory assistance must be given in good time, with adequate intervention and with optimal delivery. The measures must always be subject to critical assessment. Increased intervention must always be withdrawn if it has not led to an improvement in the patient's condition.

This step-by-step approach cannot be seen as a »recipe« to be followed strictly, but rather as a guideline which demands a willingness on the part of the hospital staff to take decisions and be flexible in the modes used.

This principle clearly illustrates the difference between conventional ventilation and Evita ventilation with BIPAP. With conventional ventilation much of the user's attention is taken up with selecting and using different modes in attempting to cope with changes in symptoms. Evita ventilation using BIPAP, however, enables attention to be focussed more on the patient.

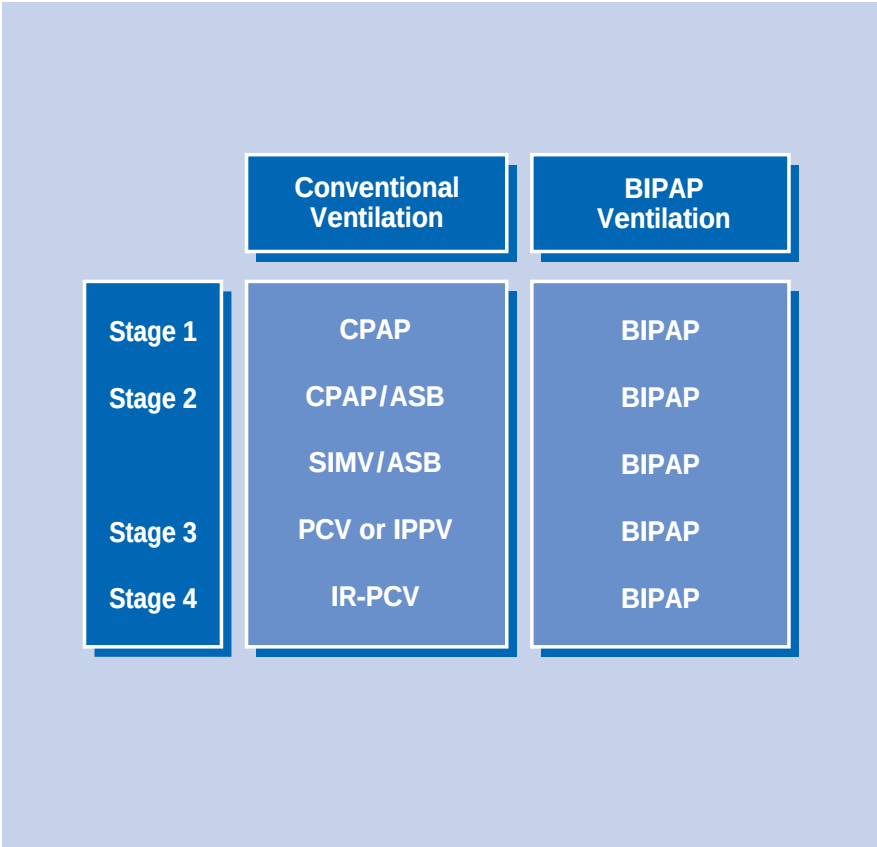

Fig. 24: Ventilation strategy based on the step-by-step approach [2].

Intervention can either be stepped up (increased ventilation) or stepped down (weaning). To pass through all stages, conventional ventilation involves frequently alternating between modes. With BIPAP ventilation, however, a single ventilation mode is used throughout the course of therapy from a maximum to a minimum level of invasiveness.

BIPAP-APRV: Ventilation with pressure release

The APRV (Airway Pressure Release Ventilation) mode was developed by a group headed by Downs [7]. From a technological point of view, BIPAP and APRV are very similar. Both modes allow spontaneous breathing at all times, with APRV employing extremely short expiratory times.

The difference between the two modes lies in the ventilation principle involved. APRV does not ventilate by delivering mechanical breaths, but rather by short periods of pressure release. APRV does not, therefore, have the inspiratory times and ventilation pressures which augmented ventilation has, but instead uses the above-mentioned periods of short-term pressure release. On the Evita ventilator, this form of ventilation is available in BIPAP-APRV mode.

Compared to conventional ventilation BIPAP-APRV avoids high pressure peaks in cases where the need for oxygenation makes a high mean pressure unavoidable.

In recent studies on BIPAP-APRV, Sydow et al. successfully treated cases of acute lung injury (ALI) [8]. The peak pressure with APRV was 30% less and better oxygenation was achieved.

The authors attributed the success of the treatment to the beneficial effect on the collapsed alveoli (atelectasis) of the constant availability of spontaneous breathing. With BIPAP-APRV, it was possible to re-inflate the alveoli using far lower peak pressures than would be the case with volume-constant ventilation at comparable I:E ratios.

On the basis of these results, BIPAP-APRV offers a much greater chance of success in treating some diseases for which the risks of complications are high when conventional ventilation is used.

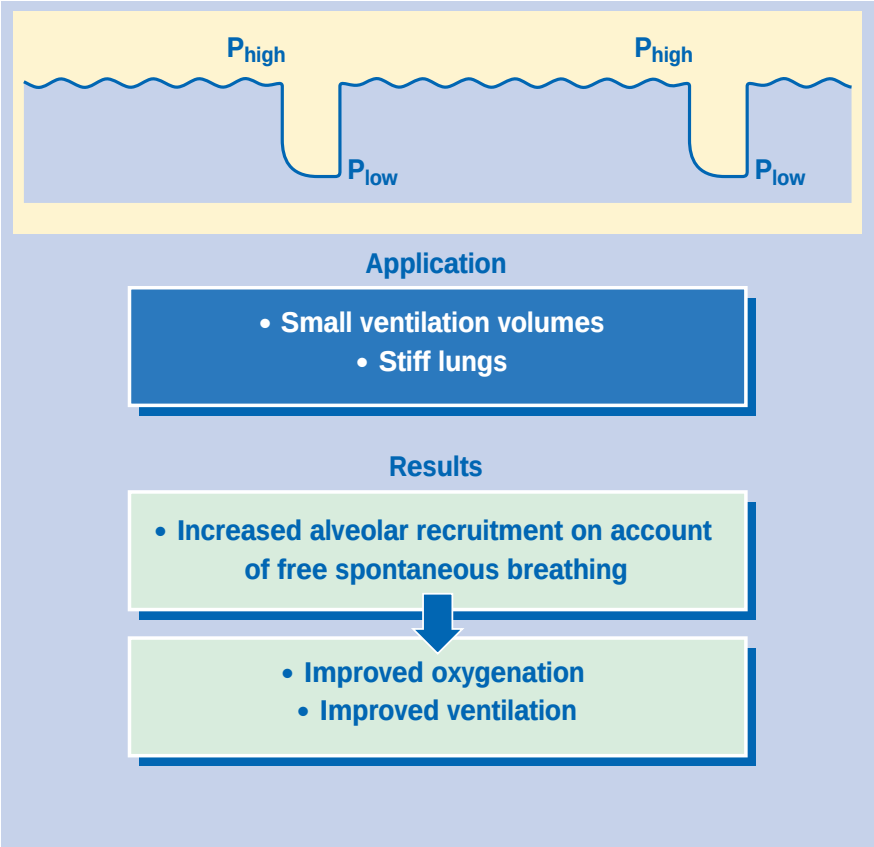

Fig. 25: BIPAP-APRV (Airway Pressure Release Ventilation).

The illustration at the top of the figure shows short-term pressure release from a CPAP level (P_{high}) in an airway pressure profile. The bottom part of the figure shows ventilation conditions in ALI (Acute Lung Injury) and results of APRV.

BIPAP – the experience to date: An established ventilation mode

Two articles have recently been published which describe long-term research on the effects of BIPAP ventilation [5][9].

The number of cases treated is remarkable but it is also significant that BIPAP is increasingly being used as standard procedure. In one situation, all patients requiring ventilation have only been treated with BIPAP for a number of years to the total exclusion of conventional modes [9].

In another instance, alternative forms of ventilation have only been employed under exceptional circumstances [5], but some 90% of patients requiring ventilation have been treated with BIPAP, irrespective of the intensity of pulmonary failure or the extent of the basic disorder.

The University Hospital of Innsbruck registered 1500 cases treated with BIPAP until 1994, which provides a suitable basis for the statistical analysis of Evita ventilation using BIPAP.

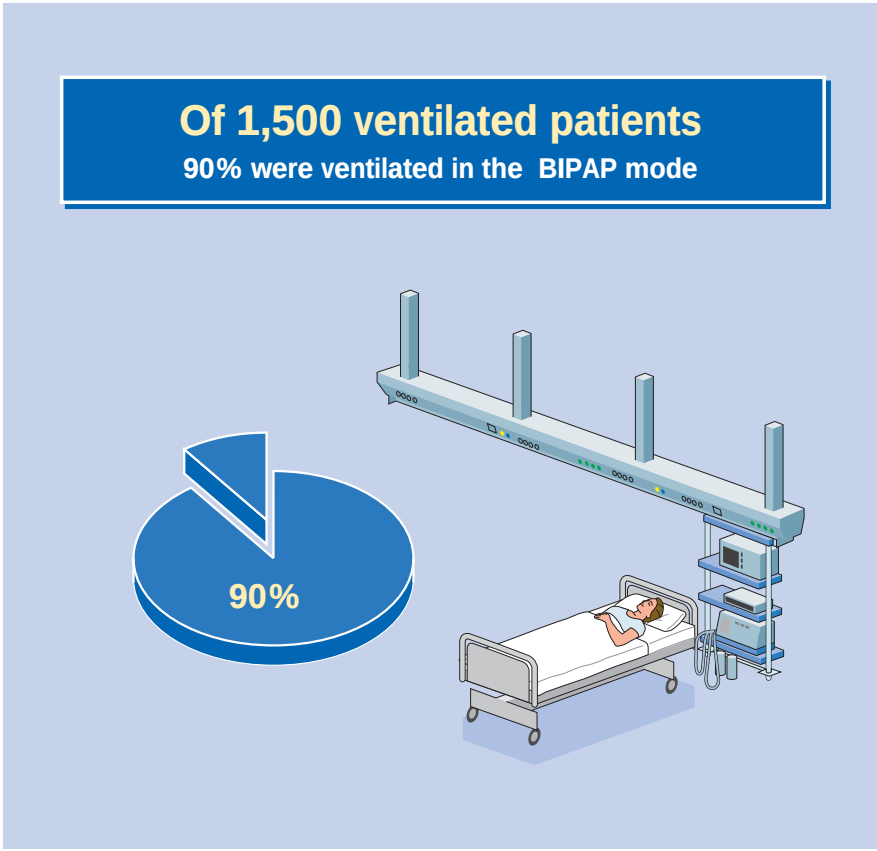

Fig. 26: Published number of cases treated with BIPAP ventilation.

The illustration shows the number and proportion of patients treated with BIPAP ventilation in the University Hospital of Innsbruck in 1994.

BIPAP – the circles of success: Spontaneous breathing

As lung function worsens, there are frequently very few choices left in ventilation therapy. Increasing the degree of intervention also increases the danger of destroying what the treatment is trying to save. In the end, complications often result in a chain of negative events which leads to an ever more hopeless situation. The effect of shear forces within the pulmonary tissue is described here as an example of such a chain of complications.

During ventilation, shear forces occur through the constant collapse and inflation of alveoli. These forces cause minor local tissue damage which is followed by firstly tissue fluid and then blood entering the alveoli. The alveolar wall becomes irritated (surfactant deficit) and the result is atelectasis. Forced ventilation is attempted at higher ventilation pressures to increase the area available for gas exchange. This produces more shear forces and completes a vicious circle.

However, there can be interactions in ventilation therapy which produce positive effects - such as the constant availability of spontaneous breathing during BIPAP ventilation.

Because fewer sedatives are used, the patient's ventilatory drive is not weakened. Over a period, the enhanced spontaneous breathing re-inflates collapsed alveoli and enlarges the area available for gas exchange. The ventilation pressure can then be reduced and, as a result, spontaneous breathing will continue to improve – particularly at the upper pressure level – providing a circle of benefit.

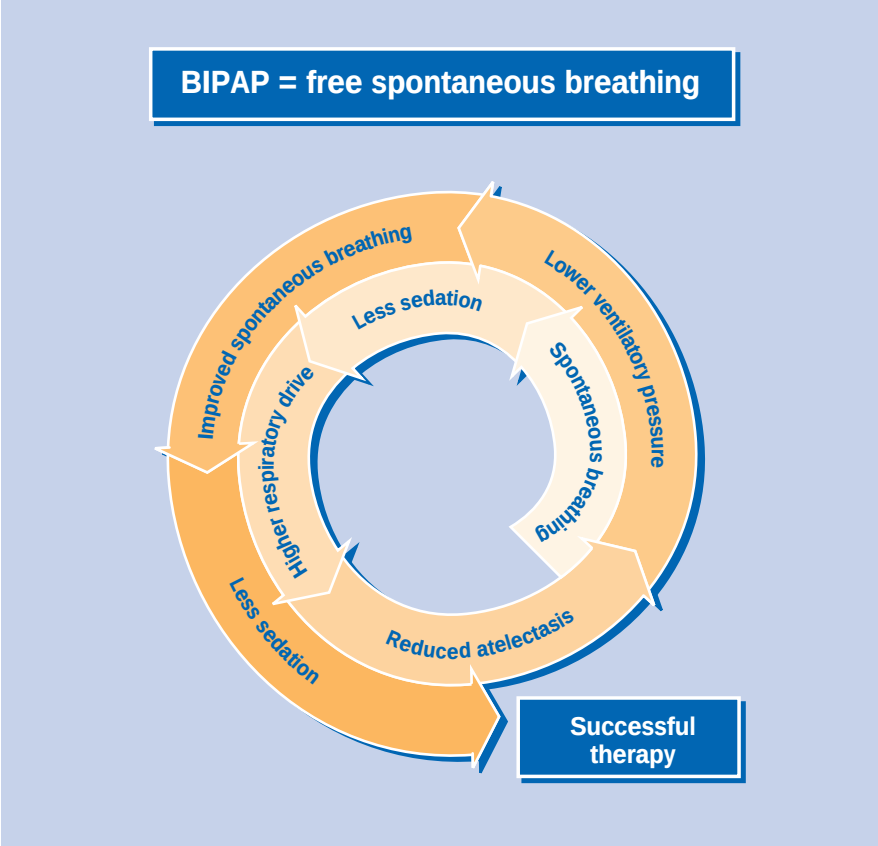

Fig. 27: Positive effects of unimpeded spontaneous breathing in BIPAP.

The illustration shows the chain of positive effects on treatment which results from freely available spontaneous breathing. The elements positively enhance each other.

BIPAP key factors of performance: Focussing on the clinical environment

To date, progress in intensive-care ventilation has generally meant ever greater complexity: more ventilation modes, more adjustable parameters to be set and yet more additional functions. The BIPAP philosophy does not follow this route.

BIPAP reduces complexity and concentrates on essentials. By covering the entire treatment spectrum right through the course of therapy, BIPAP offers greater flexibility. The therapist does not have to focus most attention on when to switch over. The measures which are necessary can be administered more sensitively throughout the period of treatment and the degree of intervention can be controlled more carefully.

However, continuous ventilation therapy with BIPAP does more than increase flexibility. It also reduces the workload on the hospital staff.

Modern ventilators may switch between ventilation modes at the touch of a button but the therapist still has to give reasons why and when to switch over and he/she has to prepare for the new mode. None of this is necessary with BIPAP.

BIPAP lightens the workload further by reducing the use of medication to relax the patient. Administering each dose of medication and checking its effectiveness are further tasks which can sometimes be completely eliminated when BIPAP is used.

The BIPAP philosophy helps clinical staff both by providing greater flexibility for therapy and by reducing the workload.

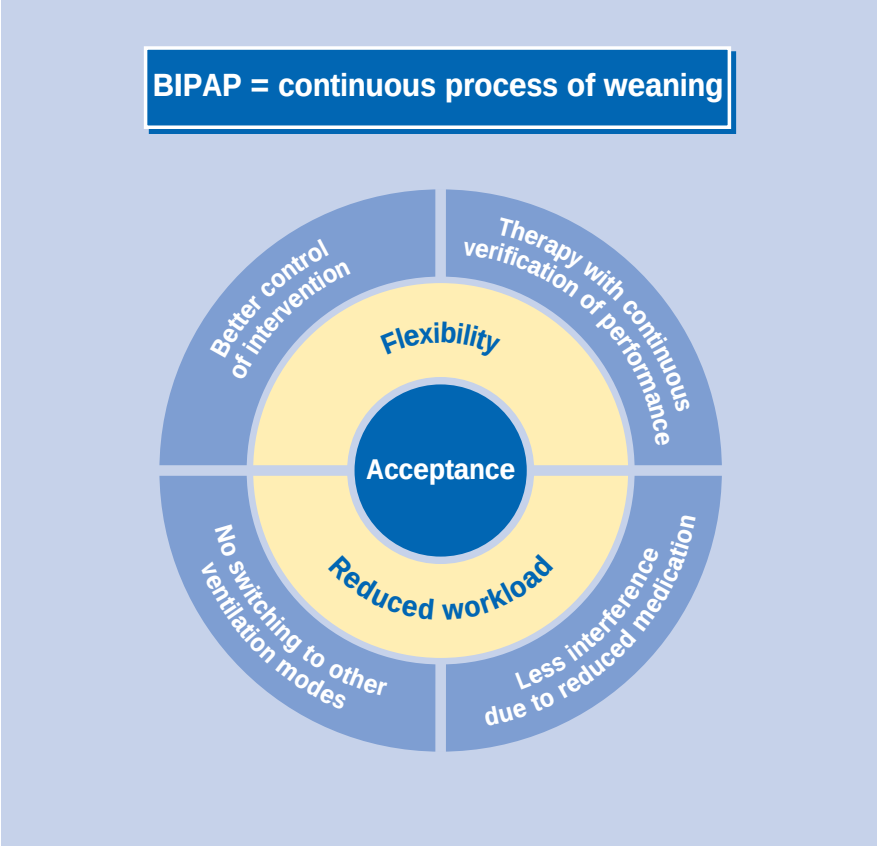
BIPAP = continuous process of weaning
Better control of intervention
Therapy with continuous verification of performance
Flexibility
Acceptance
Reduced workload
No switching to other ventilation modes
Less interference due to reduced medication

Fig. 28: BIPAP and its use by clinical staff.

The illustration shows the advantages of BIPAP and its influence on the hospital workload.

BIPAP:
Implementation in Evita ventilation

BIPAP has been an important element in Evita ventilators since it was first introduced and it has developed continuously in response to the results of clinical research and to the needs of its users.

The implementation of the second generation of BIPAP into the Evita ventilator saw the new mode fully integrated with conventional ventilation. Optional versions have also been created for special uses or to meet particular demands from users, so that BIPAP is fulfilling its original aim to offer more freedom to both patient and user.

It is possible that another phase of development could be built on BIPAP, and what has been achieved in pressure-controlled ventilation might also be repeated in the field of volume-constant ventilation.

The Evita ventilator is well placed to adapt successfully to the future. It has done this before with BIPAP and will be able to repeat the process again.

Evita 2

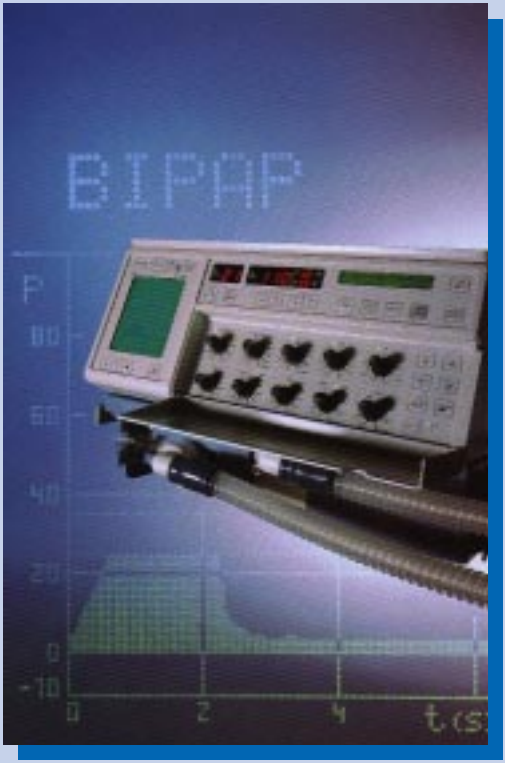

Fig. 29: Integration of BIPAP into Evita ventilation.

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